DESALINATION IN SOUTH FLORIDA

Proceedings of a Seminar
Held at MacArthur's Holiday Inn

August 21, 1987

Palm Beach Gardens, Florida

EDITOR
O. K. Buros

Sponsored by

NATIONAL WATER SUPPLY IMPROVEMENT ASSOCIATION
(NWSIA)

and the

South Florida Water Management District
(SFWMD)

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PREFACE

Desalination of brackish and seawater to produce potable water for municipal purposes is still what some might consider a new water treatment technology. Its commercial development has occurred largely over the past 25 years. The total installed capacity of desalination systems throughout the world is now about 3 billion gallons per day, almost half of which is located in the arid Middle East. In the United States, the State of Florida is a leading proponent of the technology, having over 100 desalination plants. The state still relies on using groundwater for most of its municipal water supplies; however, interest in using desalination processes to take advantage of the state's abundant brackish and seawater resources is increasing. This interest is heightened in South Florida, where the rapid population growth is stressing the existing water resources.

During this seminar, the participants agreed on the following:

1. Both now and in the future, desalination is a water resource tool that will help Florida meet its increasing water supply needs.

2. Desalination is a proven technology and can be, in many cases, a viable and cost-effective water treatment method for many areas in Florida.

3. The technology will continue to develop, especially in the area of membranes. Not only will this development assist in the economics of the process, but it will continue to increase the applications for desalination processes.

This seminar, which was held on August 21, 1987, at MacArthur's Holiday Inn in Palm Beach Gardens, Florida, was one of a series of technology transfer activities that the National Water Supply Improvement Association (NWSIA) have held in the United States. This particular seminar was co-sponsored by the South Florida Water

Management District (SFWMD). This seminar was the direct result of the interest and initiative of one of SFWMD's staff, Mr. Nagendra Khanal.

These proceedings contain, for the most part, papers that were presented by the various participants on their respective topics. However, the introductory remarks, the question-and-answer periods, the round-table discussions, and the summary remarks contained in this proceedings were derived from the video tapes which were made of the sessions. All of these sections were first transcribed and then edited to bridge the gap between the spoken and written word.

The NWSIA has a history of interest in desalting technology in Florida. It has held two national conferences in the state: one in Sarasota in 1978 and the other in Orlando in 1984 as well as sponsoring a number of other desalting seminars in Florida.

NWSIA was formed in 1973 to promote the appropriate use of desalination, water reuse, and other water sciences. Members include water utilities, manufacturers and suppliers of related equipment, consultants, academicians, and other interested individuals.

Through its publications, conferences, and technology transfer seminars, NWSIA provides a forum for discussing a wide variety of water supply improvement topics. The Association works closely with other water industry-oriented organizations, giving members access to the entire water supply community. NWSIA is affiliated at the international level with the International Desalination Association (IDA) and in the United States with the California Association of Reclamation Entities of Water (CAREW).

The Board of Directors and staff of the NWSIA were pleased to work with our co-sponsor, the South Florida Water Management District, in organizing this seminar and we hope we can work together on additional seminars in the future.

O. K. Buros
Gainesville, Florida
Proceedings Editor

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DESALINATION IN SOUTH FLORIDA

August 21, 1987

INTRODUCTION AND WELCOME -- NWSIA

by

Howard W. Harlow, Manager
Englewood Water District
Englewood, Florida

I am the President of the National Water Supply Improvement Association (NWSIA) and I would like to welcome all of you to this one-day seminar on desalination in South Florida. The purpose of NWSIA is for the dissemination and promotion of: desalination, water reuse, and new water sciences for the improvement of the water supply of the United States and the rest of the world. NWSIA has been giving technology transfer seminars for a number of years. This one is a joint effort with the South Florida Water Management District and we hope that when you leave here today that you will have a better picture of the water needs of the area in which you are now located and that you will also have a better understanding of what desalination and what the new water sciences can do for the improvement of the quality of life in South Florida. I would now like to introduce to you Mr. Tilford Creel who is the Deputy Director of the South Florida Water Management District which is the co-sponsor of this seminar.

This paper was prepared by the editor based on a recording of the presentation. Where deemed appropriate, the presentation has been edited for clarity.

INTRODUCTION AND WELCOME -- SFWMD

by

Tilford Creel

Deputy Executive Director

South Florida Water Management District

West Palm Beach, Florida

If you had been here two weeks ago when the Professional Golf Association of America showed up for their golf tournament, you would have understood that they were not too excited about playing in this heat. However, we think this is a pretty nice part of the country. Although we like it very much and call it the sunshine state, we can get an over-abundance of sunshine which we have at this particular moment.

In South Florida, we have a very nice climate all year long but the seasonal variation of the sun changes very quickly the amount of rain and water that we have and its retention. Currently, we are in the middle of our wet season but no hurricanes or tropical storms have come by and our lake levels are starting to drop.

Our dry season, which is in the winter and spring time, is the time when we get most of our tourists. It is beautiful weather but we get very little rainfall during that time. We have had, for two years, sort of wet dry-seasons. We have enjoyed them as they replenished our reservoirs but it illustrates the seasonal variation and fluctuation that we have in South Florida. I think this conference is most apropos in looking at the alternative ways of using our freshwater sources. We are experiencing a fantastic population growth in South Florida. The state has passed Michigan, Ohio, Illinois and some other states that were larger than we were two or three years ago. We are now the fourth largest state by population in the country. We expect to be the third largest state by the turn of the century.

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If you are going to retain the quality of life and the attractions that we have in South Florida, then we should be concerned about what we have had in the past which is an almost unlimited supply of inexpensive freshwater on a year round basis. The unlimited availability of this inexpensive source of freshwater is going to change and that is the key item that should concern us.

We get 55 to 60 inches of rainfall per year. However, 45 to 50 of those inches are lost very quickly by evapotranspiration. During our dry winters and warm springs, our seasonal tourists are at their heaviest. We normally get through this period if our reservoirs are pretty well filled through the wet summer months. If we have our reservoirs sufficiently filled we are okay, but if not, then we get into a drought situation. The water supply problems that used to occur during a 20 year drought now occur with 10 year droughts, problems of 10 year droughts are now associated with 5 year droughts, and 5 year problems are now occurring in the 2 and 3 year drought cycles.

This means you have to use water more wisely. It does not imply any panic situation but it does mean that we are going to have to use alternative strategies in our water supply plans.

Even though desalination processes are becoming more cost effective, I would like to remind everybody that I think other alternative water resource strategies must be explored and utilized where appropriate.

The District has a far flung mission. We are responsible for: flood control, water supply, for water quality protection, and environment protection. Recently, the legislation put us into another business, the inter-district supply and regionalization of water, which again you may be discussing here.

One of the first things that we are going to be doing in that area is to look at the water supply in Brevard and Osceola counties. What effect that has on the interconnection of other counties, certainly no one in this room can tell you at this particular time. But I will tell you that the legislature, the Governor, and certainly our governing board has said that we want you to look at other things that you are doing and, in the future, the District may have other missions.

I would like to quickly touch upon some of the initiatives we have taken so far in the areas of water supply and in demand management. In the field of water supply management, the District has focused on encouraging water reuse to meet non-potable irrigation needs. In cooperation with wastewater treatment operators, the District is planning to study motivational rate structuring and regulatory requirements to promote the use of effluent for irrigation on golf courses and other large landscaped areas. Reverse osmosis and desalination technologies are another approach we are developing as well as protecting coastal aquifers from the seasonal overuse.

According to statistics, 80 percent of the people who come to Florida are going to reside close to the coast. This results in a high demand on the coastal aquifers. As most of you who live in Florida know, 95 percent of our water comes from our groundwater sources.

Under our consumptive water permitting program, the District is requiring area utilities to prepare comprehensive conservation plans. Ultimately, we hope to encourage a trend toward regionalization of water supplies as a method of dealing with localized shortages. On the conservation side of our plans, which we emphasize in our consumptive use permits, we have changed a little bit. We no longer give these water use permits for 5 years to 10 years. We do them for 2 years now, requiring a responsive conservation plan to go with it. We want to know how wastewater is going to be used. You are going to see more of that trend because we are concerned about meaningful wastewater reuse.

On the demand management side, we have developed a number of products to effectively reduce water consumption to its most efficient use. As 50 percent of the water used in South Florida is used for landscape irrigation, a model landscape code has been developed in our region. We are very proud of that work being done and the acceptance by the counties of that model landscape code. We are also looking at the promotion of xeroscape. We had a nationally attended conference in Ft. Myers last year, I think between California, Texas, Colorado, and ourselves, we are leaders, as we see it, in xeroscape. We are not going to become another Phoenix, Arizona, but we are going to encourage the use of the kinds of plants that are normal to Florida and, hopefully. this will help to reduce the amount of water used for that purpose.

We are using some demonstration projects involving public utilities. Over in Naples, we are working on a cost program. Other programs include water recycling, conservation rate structuring, leak detection, and various residential programs. Additionally, we are involved in data collection to monitor the effectiveness and feasibility of saltwater to freshwater conversion and the treatment and disposal of brine as part of developing sound alternative water technologies. We know that desalination is still an expensive alternative but it is becoming cheaper and certainly the experts today are going to point out to you how cost effective it is becoming. By the early 1990's, we would think it would become perhaps one of the most used alternative sources employed in South Florida. Already there are many desalination plants existing and operating in Florida and we have seen significant growth in desalting over the last few years.

I would like to close by welcoming you to South Florida and to the South Florida Water Management District. I appreciate the efforts being made to bring together these experts to look at desalination. We do think it is a fine alternative source of water and we think that if the quality of life in South Florida is to be retained for the people that are here and going to come, that this alternative source will have be encouraged.

A WATER RESOURCE OVERVIEW OF SOUTH FLORIDA

by

Peter B. Rhoads
Director of Resource Planning
South Florida Water Management District
West Palm Beach, Florida

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by

Peter B. Rhoads
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From a water resource planner's perspective, we are in for some interesting times during the next 10 to 20 years. The reason for that is that the days of easy answers and cheap water supplies are over, or at the very least, coming to an end.

Right now, in the area south of Lake Okeechobee, we have about 5 million people. The best forecast available to us indicates that within the next 25 years we are going to have 7 million people in that area. From a demand perspective what that means is that the 2.3 billion gpd of water being used currently, will increase to about 3 billion gpd of water within a 25 year time horizon.

Right now, from a water supply and shortage viewpoint, there are specific areas south of Lake Okeechobee that do not have sufficient water availability to get through a drought. In actuality, most of the areas are vulnerable to the type of severe drought that California had during 1976-1977. South Florida is also vulnerable to that but there are some ways to deal with this.

From a regional viewpoint, there have been alternatives to increase regional water supplies that have been on the books for a long time. For Lake Okeechobee, the Corps of Engineers proposed storing more water in the lake. Currently, the maximum level is 15-1/2 to 17-1/2 feet above mean sea level. Congress has authorized going up to 21-1/2 feet but that does not appear to be very practical. The reason for that is environmental, primarily. Lake Okeechobee has a very productive literal zone with marsh plants that the fish are

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dependent upon. Looking at it from a water resource values viewpoint, there does not appear to be much chance that we are going to be able to raise Lake Okeechobee and store more water in that area within the foreseeable future due to the environmental constraints.

Backpumping--In the lower east coast where we have most of the people, one of the traditional water resource alternatives is to pump some of the excess water from the coastal region back into the water conservation areas for storage. This has been on the books for a long time. There are a couple of problems with this, with hydroperiod being a major one. It affects the amount of water in the traditional Everglades. When the plans were originally developed nobody realized that you had to have a very carefully maintained water level to keep a healthy marsh and if you put more water in there, it would result in environmental changes. So the picture for backpumping is certainly not clear at all.

In addition to water levels, there are nutrients. The loading of phosphorus and nitrogen in the natural habitat results in changes. That further makes backpumping questionable.

Well field development--Most of us in South Florida drink water that has been pumped out of the ground and, in most cases, treated. The expansion of existing, and development of additional, well fields seems to be the primary alternative in the immediate future but that alternative, both on the east and west coast, is running into difficulty. I think we are all aware of the rapidly rising concerns about groundwater quality. Past industrial land uses have contaminated portions of the groundwater and it is becoming more and more difficult to find good freshwater well field sites. Additionally, it is becoming more difficult to expand existing well fields both because of saltwater intrusion and the impact of the well field's cone of depression on wetlands.

So there are water quality and environmental concerns, and in addition, if you have to go further out to put in a well field, that means you have to put in a longer pipeline to be able to pump the water to where the people are located. The farther you go, the more the costs go up.

Another alternative is deep well or aquifer storage. In this technique, excess water is pumped during the wet season down into the upper Floridan aquifer, stored, and then withdrawn during times of need. That may be an alternative that is viable in the future. At the current time though, there appear to be some difficulties that are going to need to be worked out and it needs more research but it may be an option.

So having run through the major alternatives, I am down to desalination. And, I think, from a district perspective, we feel this alternative warrants some serious consideration by those of you in the water supply business as well as those of you who are elected officials and have to make decisions on the provision of public water supplies.

We believe that NWSIA has brought together for us an outstanding group of experts from around the country and we hope that this is going to be an informative and helpful technology transfer seminar for you today. Thank you for coming.

ASSESSING DESALTING NEEDS OF SOUTH FLORIDA

by

O. J. Morin
DSS Engineers, Inc.
Fort Lauderdale, Florida

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ASSESSING DESALTING NEEDS OF SOUTH FLORIDA

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O. J. Morin

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Fort Lauderdale, Florida

INTRODUCTION

The annual rainfall over South Florida averages 60 inches per year. This falls over an area of approximately 12,100 square miles resulting in 38.72 million acre feet of water or an average of 34,660 million gallons per day (mgd). With an estimated population of 4.7 million in 1987, this is about 7,375 gallons per day (gpd) per person. Yet there presently is a shortage of water in some areas of South Florida. Without proper planning, further widespread shortages in water supplies may occur in the future. This paper will examine and discuss desalination as a viable, cost-effective method for meeting the future water demands of South Florida. This discussion will include a description of desalination technology currently available and will provide a cost comparison of desalination methods and conventional water treatment.

How can South Florida have shortages in natural water supplies with this amount of rainfall? Unfortunately, rain does not fall where we want it and when we want it. Most of this water is lost to the sea by surface runoff to canals. More is lost through ground seepage (and then to the sea) and by evaporation. Additionally, most of the rain falls during only 6 months of the year and some years, South Florida has only about half of its average rainfall.

This is further complicated by the fact that there is very little water storage capacity in South Florida. While there is a total of 861,500 acres (1,346 square miles) of storage area, water levels are restricted so this area can only store about 1.17 million gallons of water. Much of this is lost by evaporation and ground seepage.

Consequently, as the population in South Florida increases, suitable water supplies will become more scarce. The basic challenge then is how to provide adequate supplies of water in the future for the Everglades National Park and agricultural, municipal, and industrial use without adversely impacting man or nature, or at least minimizing such impacts. There are a number of alternate methods to successfully accomplish this; desalination is one of them.

The area of South Florida considered for this discussion consists essentially of all the area south of the north shore of Lake Okeechobee as shown in Figure 1. This area includes all or part of 12 counties covering approximately 12,100 square miles. This area has been divided into three main service areas, as follows:

I	The Lake Okeechobee
II	The Lower East Coast
III	The Lower West Coast

The current estimated population and projected growth for the three areas is shown in Figure 2. Review of this figure shows an expected average increase of approximately 1,000,000 people each decade.

SOUTH FLORIDA WATER DEMAND AND SUPPLIES

DEMAND

Future water demand for these service areas was estimated by the U.S. Army Corps of Engineers (COE) in 1968 and by the South Florida Water Management District (SFWMD) in 1978. Figure 3 shows the demand projected by the COE and SFWMD for all other service areas as well as the total projected demand.

The water consumption for each area may be seen by comparing the per capita consumption over the period as follows:

Area	Per Capita Consumption (gpd/person)
I	1335 to 1990 gpd
II	300 to 333 gpd
III	330 to 414 gpd

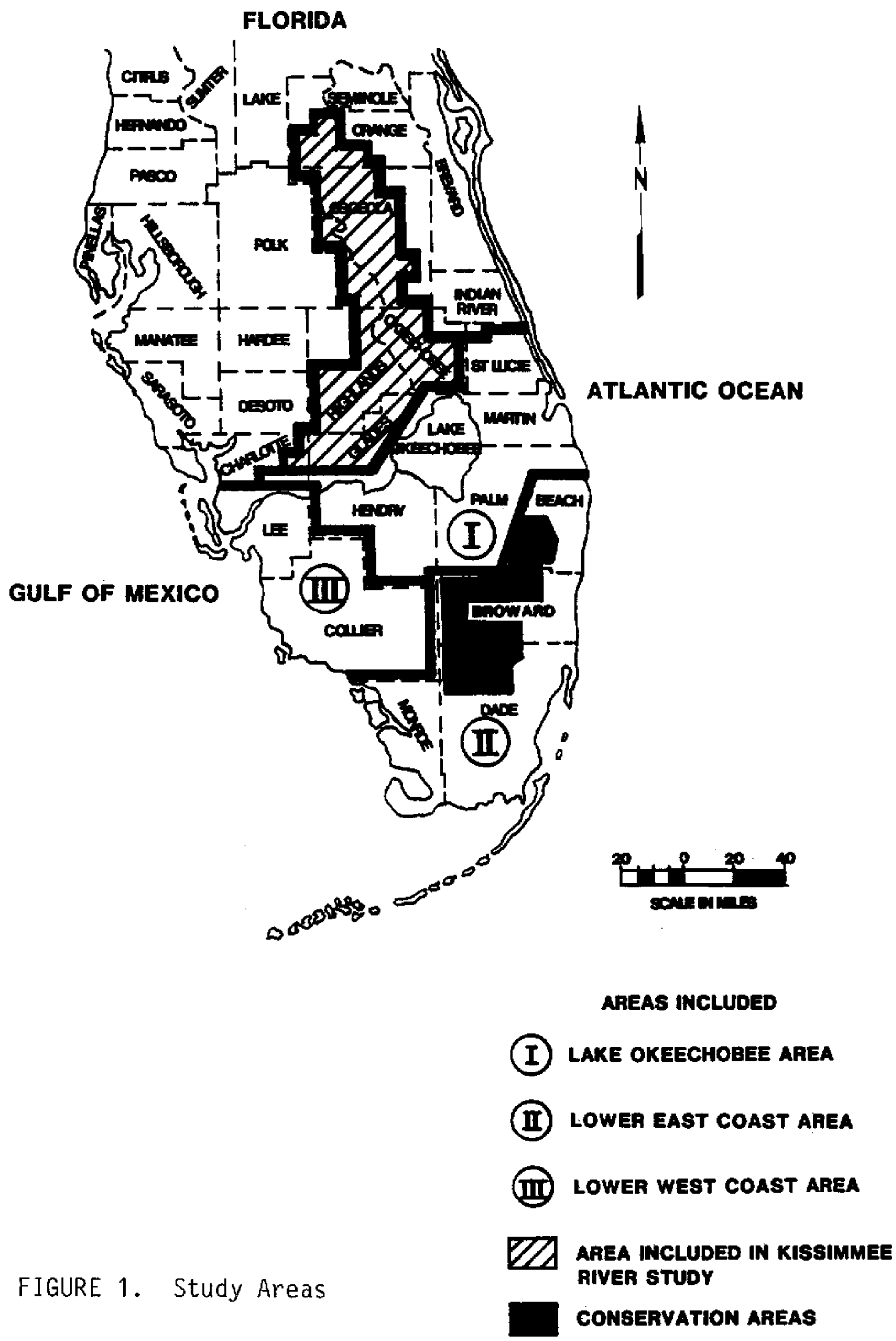

FIGURE 1. Study Areas

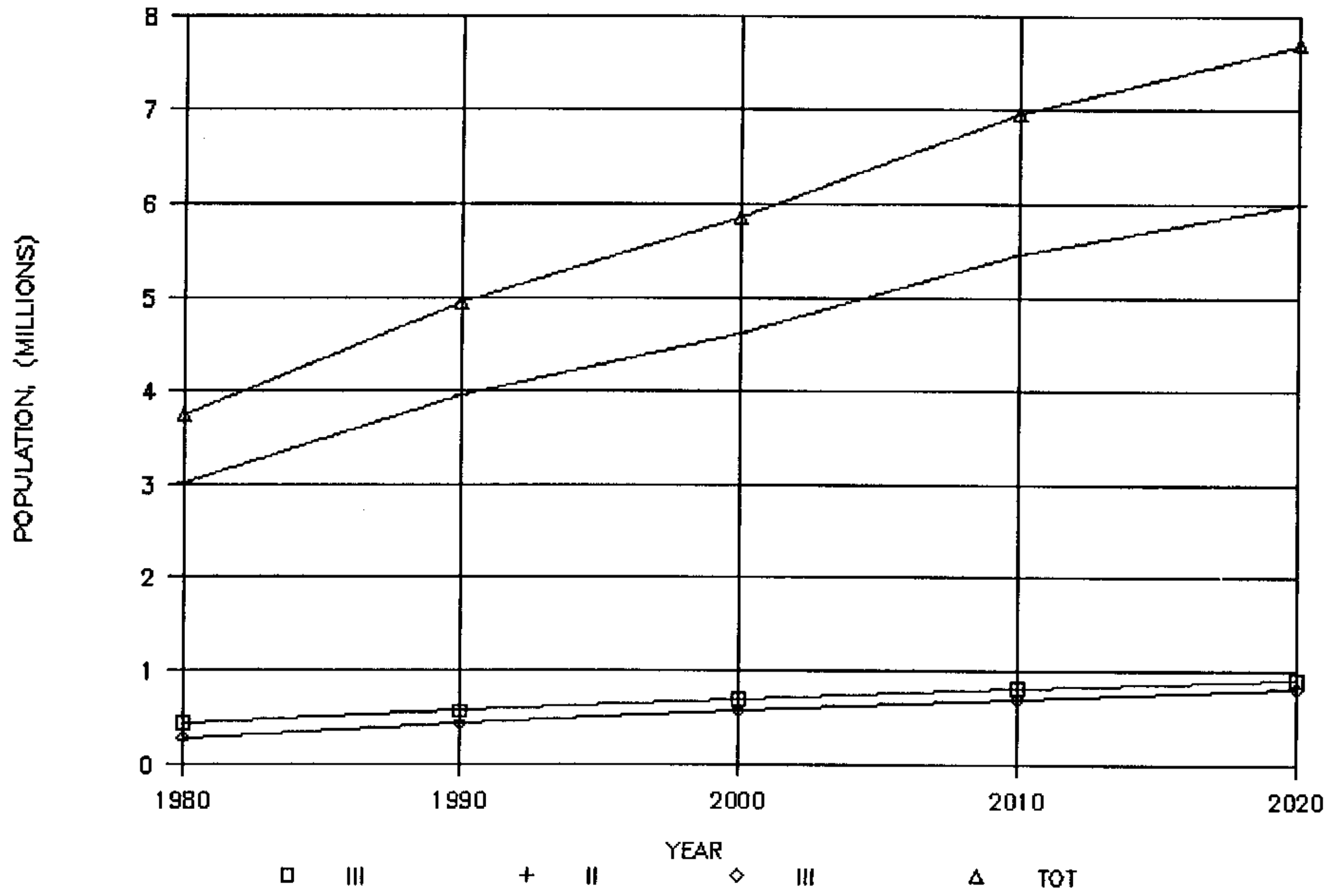

FIGURE 2. Projected Population Growth, South Florida

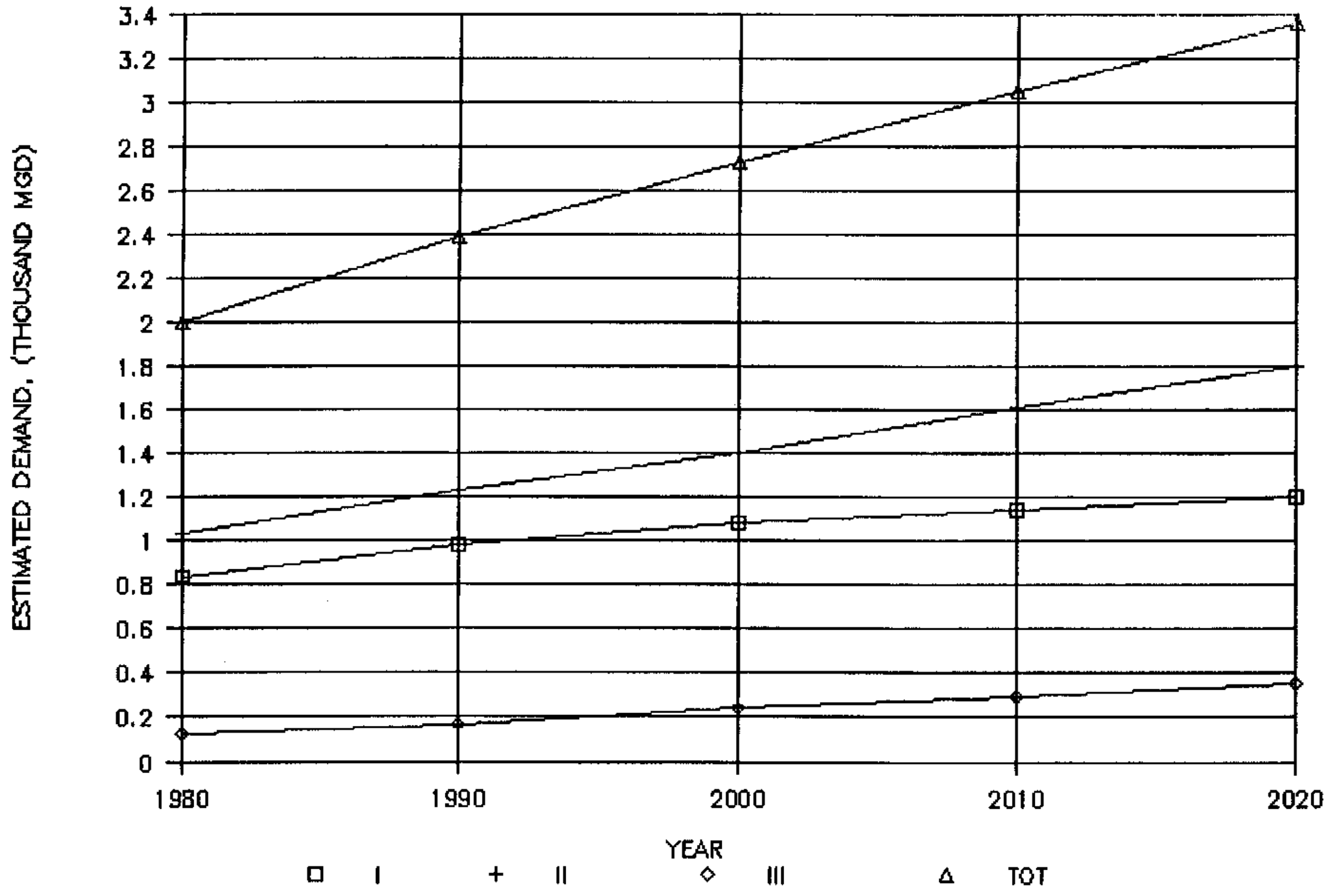

FIGURE 3. Projected Water Demand, South Florida

It should be noted that Area I is largely an agricultural area requiring large amounts of water used for this purpose while the requirements for Area II include 280 mgd each year to the Everglades National Park.

SUPPLIES

The present conventional water supplies are from Lake Okeechobee and the conservation areas, and from wells into groundwater aquifers. The present surface storage areas have a capacity of 1.168×10^6 million gallons between the regulated maximum and minimum levels. While this seems large, much of this is lost due to evaporation and ground seepage.

Surface water supplies are fixed by the amount of rainfall and the storage size. These are delivered to the service areas via pumping stations and canals. Further development of well fields, drawing from the Biscayne aquifer, can be accomplished in order to increase supplies. The total deliverable (supplies) for the three service areas along with the surplus/shortages are shown in Figure 4, Lake Okeechobee Area; Figure 5, Lower East Coast Area; and Figure 6, Lower West Coast Area. The estimated supplies are based on careful development of well fields in each area. The surplus/shortages for all three areas are shown in Figure 7, taking into consideration that Lake Okeechobee deliveries may be more equitably distributed between Areas I and II.

These projections are average daily requirements over the year and do not reflect shortages during dry months of the year when daily demands are higher but supplies are more scarce. Thus, deficits in supply to these two areas may start occurring during the February through May period before the year 2000. The total deficit in all three areas may reach 428 mgd by the year 2020 without the use of desalination or other means to augment the present sources of supply.

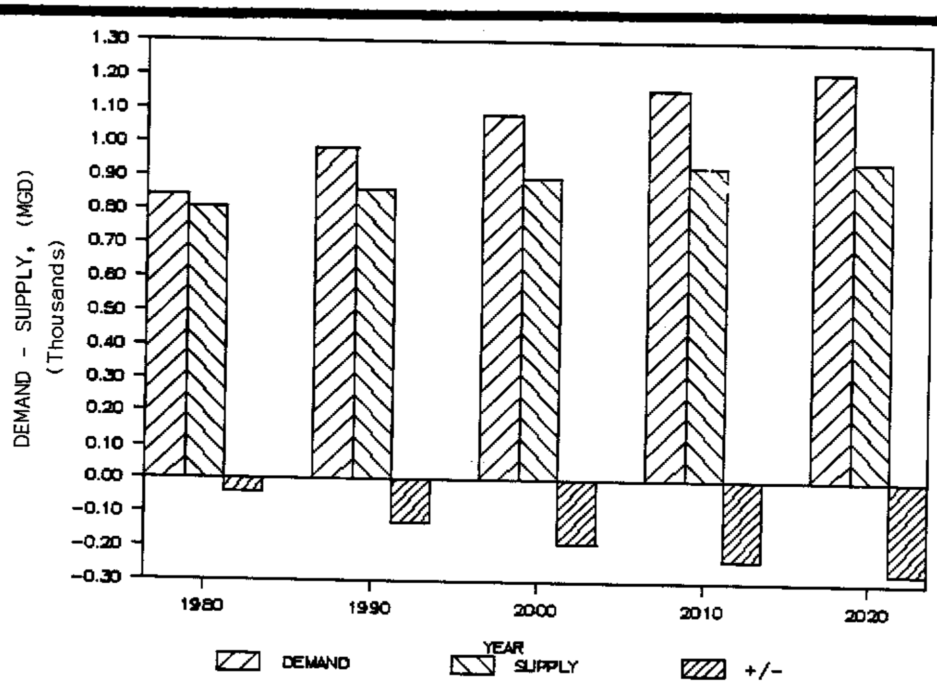

FIGURE 4. Estimated Water Demand/Supply, Service Area I

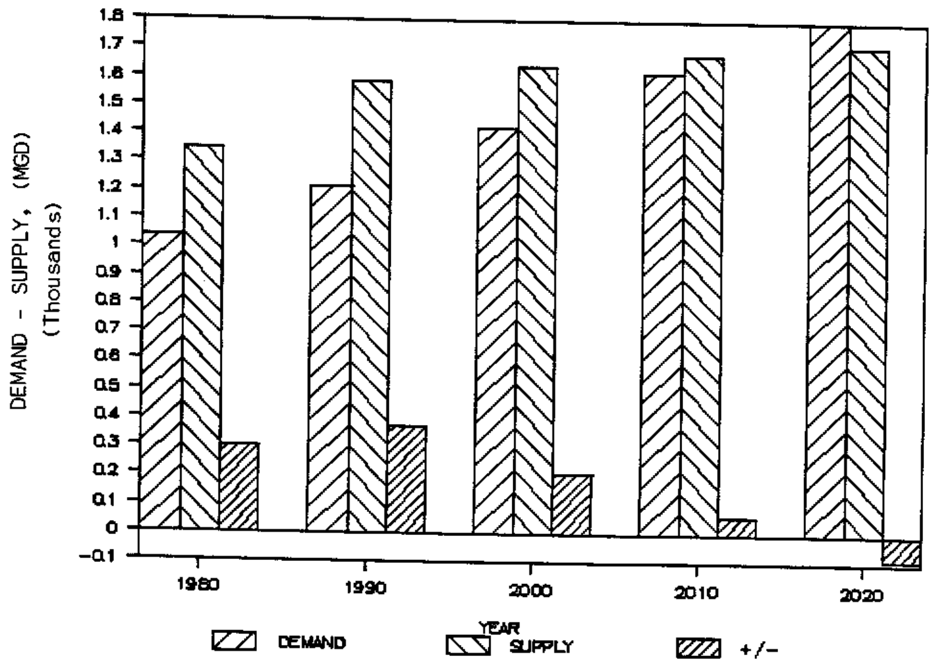

FIGURE 5. Estimated Water Demand/Supply, Service Area II

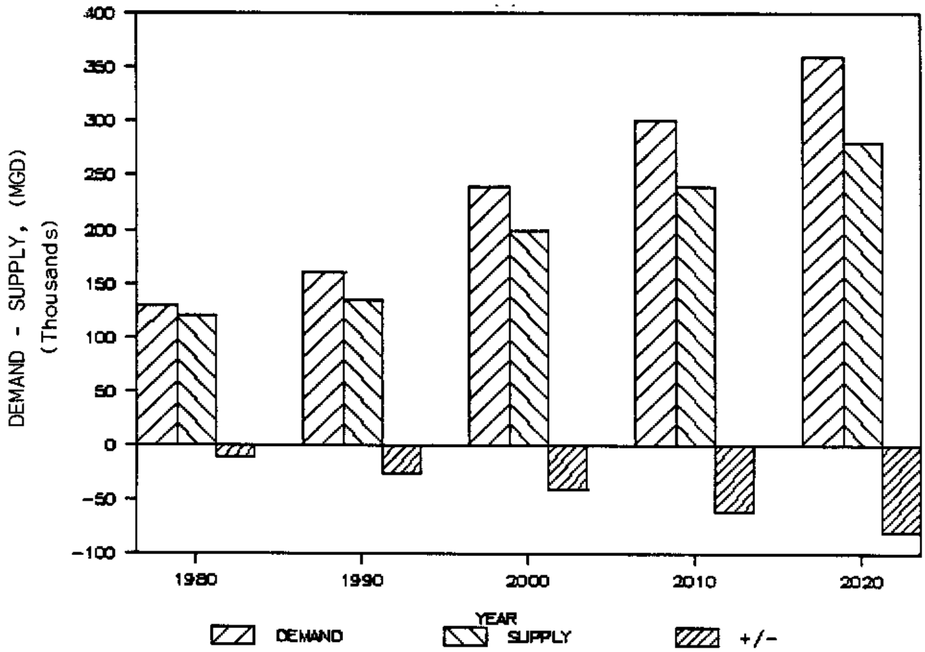

FIGURE 6. Estimated Water Demand/Supply, Service Area III

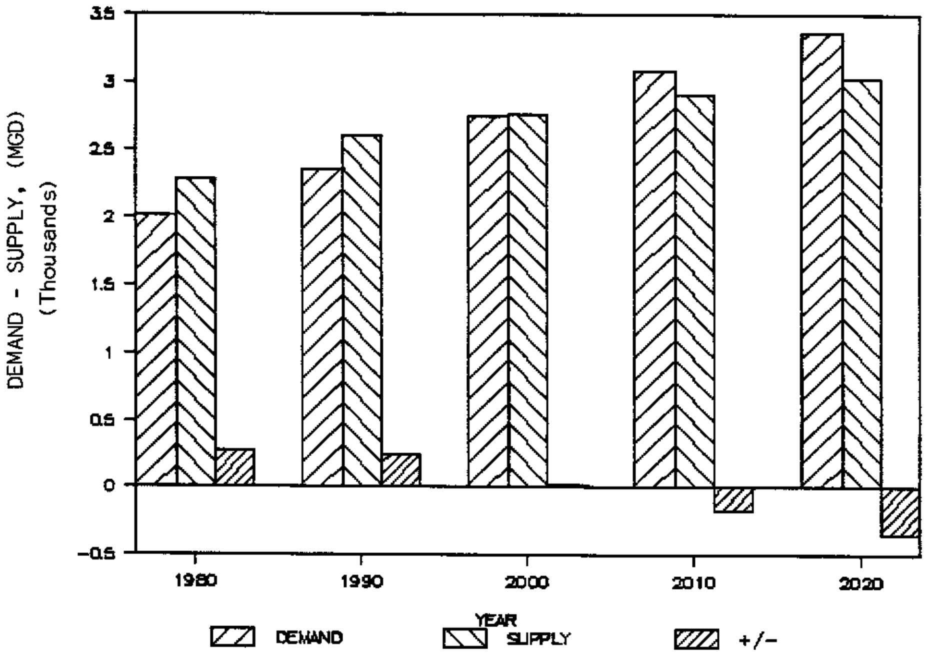

FIGURE 7. Estimated Water Demand/Supply, All Service Areas

DESALINATION

The first modern desalination plant to supply municipal drinking water in Florida was a 2.6 mgd multi-stage flash plant at Key West completed in 1967. In 1971, an electrodialysis plant went into operation on Siesta Key and two reverse osmosis plants with a total capacity of 1.13 mgd began operation in 1972. By 1986, there was a total installed desalination capacity of approximately 54 mgd in Florida. Of this, 37.3 mgd of capacity (70 percent) is located in the three areas of the South Florida Water Management District.

The growth in desalination plant capacity in Florida from 1965 to 1986 is graphically shown in Figure 8. The approximate installed desalination plant capacity in each area as of 1986 is as follows:

Area	Plant Capacity (mgd)
I	6.2
II	6.4
III	24.7
TOTAL	37.3

SOURCE WATER SUPPLY AND DISPOSAL

For convenience in discussions of desalination, water is divided into five classifications as shown below:

- Freshwater
- Brackish water
- Seawater
- Brine
- Wastewater

Freshwater generally refers to water with total dissolved solids (TDS) of up to 1,000 mg/l; brackish water from 1,000 to 35,000 mg/l; and seawater from 35,000 mg/l. Brine is the solution remaining after feedwater has passed through a desalination process and some of the pure water has been removed.

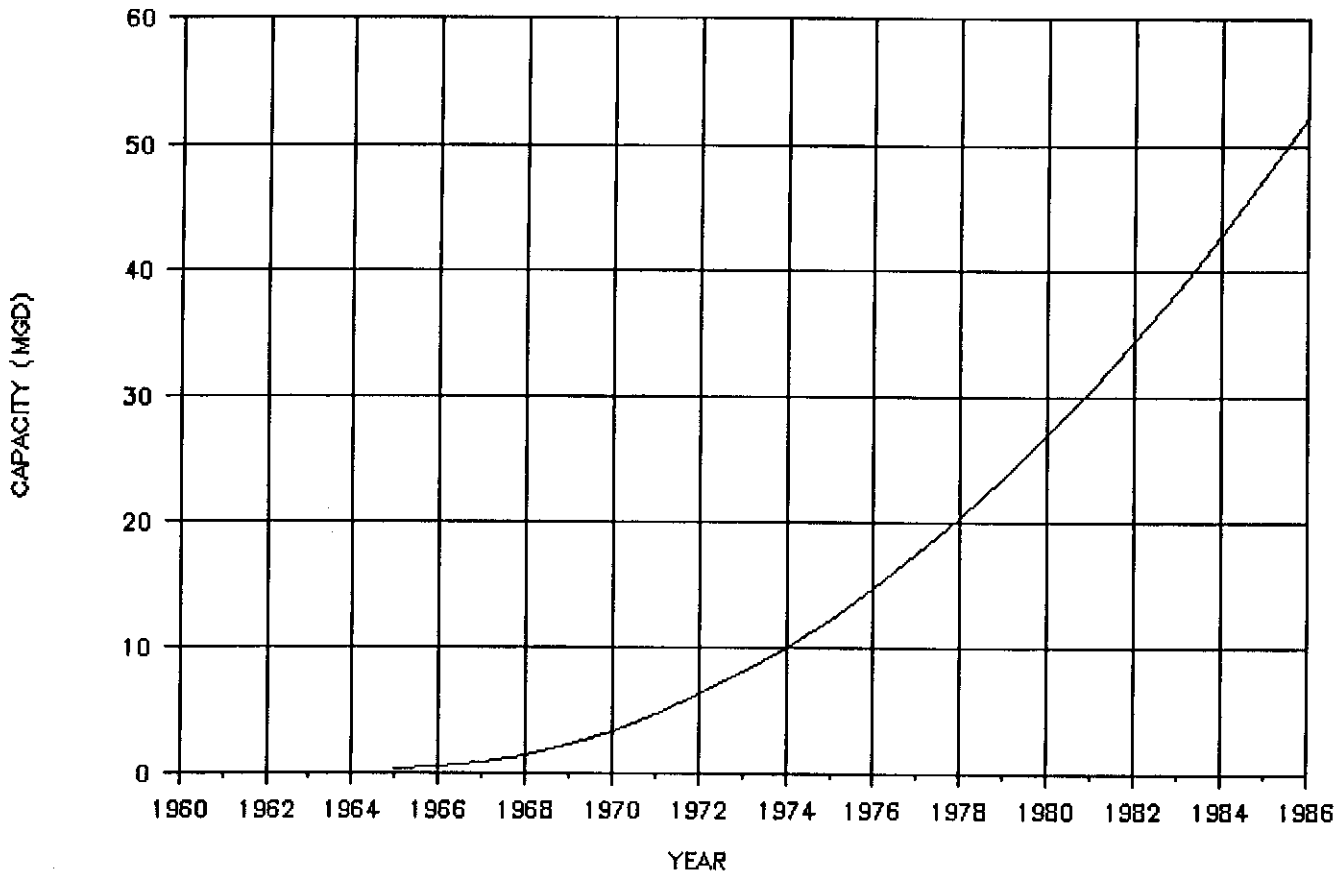

FIGURE 8. Installed Desalination Plant Capacity, All Types

Brackish water is found in lakes and streams and under the earth's surface as groundwater. When it is available in sufficient quantity and/or replaced as used, it is an important source of feedwater for desalination. Seawater is available in abundance along ocean coasts and can be used as feedwater for desalination. Since desalting seawater is more energy-intensive than desalting brackish water, it is usually considered for desalination only when sufficient brackish water is not available. Wastewater and agricultural drainage water can also be used as feedwater to a desalination process.

Because of the highly variable quality and quantity of these types of water, desalination of these for direct potable use is generally not considered; however, treatment by desalination alone or in conjunction with other means may be cost-effective for industrial use, agricultural use, or groundwater recharge.

SOURCE DEVELOPMENT

The long-term availability of raw water in the required quantity and quality is the single most important factor in ensuring the technical and economic viability of a desalination facility. In order to properly design a desalination system, the characteristics of the raw water supply must be determined and specified. These characteristics include dissolved and suspended solids, microbial content, temperature, and others. The change in these characteristics with time must be established through testing and from reliable estimates of future water quality. This is particularly important for brackish groundwater sources where future quality may change due to the quantity withdrawn from the aquifer.

All of the desalination processes require pretreatment of the raw water supply before the actual desalting step. The extent and effectiveness of this pretreatment step can be affected by the care taken in the development of the raw water source. Wells used to collect groundwater must be carefully designed and constructed based on extensive hydrogeological testing and sound engineering. Extreme care must be exercised in locating surface intakes to minimize suspended matter in the supply water.

AVAILABILITY OF SOURCE WATER IN SOUTH FLORIDA

Seawater for desalination is in abundant supply all along the coast of Florida. The seawater can be obtained via "beach wells" or surface intakes. Point sources are becoming more limited, however, due to use of coastal areas for recreational and residential purposes. Furthermore, seawater desalination is extremely energy-intensive and more expensive than desalination of brackish water.

Brackish water of various quality is available in aquifers underlying all of South Florida. The main one is a confined aquifer known as the Floridan aquifer which extends from approximately 500 feet to 2,000 feet below sea level. The range of water quality from this aquifer is from 2,000 to 8,000 parts per million (ppm) TDS depending on exact locations and depths. This is the general condition in southeastern Florida. In southwest Florida, the geology is much more complex with up to 10 separate, confined water-bearing zones present. Each has a different production rate and quality of water. Feedwater for desalination is commonly withdrawn from the Hawthorn formation or the Suwannee limestone formation at depths from 250 feet to 900 feet. The water from these aquifers is generally less saline, ranging from 1,000 ppm to 3,500 ppm.

For any specific site in South Florida it is necessary to drill a number of wells and test pump them at various depths to establish the desired producing zone and water quality. An analysis should be made to predict long-term water quality changes. Long-term changes in the quality of water being pumped from production wells is commonly caused by slow leakage of poorer quality water into the producing aquifer through adjacent confining beds and from seawater intrusion. This type of water quality change can be modeled and reasonably accurate predictions can be made of the long-term quality at different withdrawal rates. The system can then be designed to minimize long-term quality changes and designed initially to treat the final predicted feedwater quality.

DISPOSAL OF BRINE AND WASTES

Waste brines from desalination plants are generally in the range of 10,000 to 20,000 ppm TDS for brackish water plants. The disposal of wastewater brines can present significant engineering and economic challenges.

The waste effluent from a desalination plant located on or near a sea coast can usually be discharged to the ocean or large estuary with a minimum of pretreatment dilution. In general, direct discharge of the waste brine without treatment into a freshwater stream, lake, or other water course cannot be made without degrading the water quality, and laws prohibit such discharge.

Injection into subsurface strata is frequently used for disposal of waste brines at inland sites. Such disposal is feasible only at locations where underground formations for receiving the brine are suitable. In South Florida, injection of wastes into the Boulder Zone below the confining beds is allowed. Disposal of other wastes into this zone is currently occurring. This requires injection wells of a minimum depth of 3,000 feet.

Other methods of disposal include evaporation from surface brine disposal ponds which finds application mainly in warm, dry climates with high evaporation rates and low land costs. In South Florida, evaporation ponds are usually not economical. Further concentration of the waste brine by additional stages of reverse osmosis or by forced evaporation and then injection into deep wells may, in some cases, be the most cost-effective option.

DESALINATION PROCESSES

Currently, there are two general categories of commercially available types of desalination processes applicable to potable water production in South Florida: distillation and membrane. Under these two processes the following methods are available:

DISTILLATION	MEMBRANE
Multi-Stage Flash Evaporation	Reverse Osmosis
Multiple Effect Evaporation	Electrodialysis
Vapor Compression	
Diesel Driven	
Electrically Driven	

DISTILLATION

This process is commonly used for large seawater desalination plants worldwide and can be used for any type of feedwater. There are many variations of distillation processes but all involve the basic principle of evaporating pure water from the saline sources and then condensing this vapor to produce the freshwater.

Distillation produces a high quality water with TDS in the order of less than 1 mg/l. The principal form of energy input in distillation is thermal energy, usually steam. Low cost heat sources, therefore, result in lower water production costs. One of the most frequently used means of obtaining low cost thermal energy is the utilization of low pressure steam in a dual purpose water and power plant.

A distillation type desalination plant is usually optimized for each specific application to minimize the overall costs of producing water. This optimization depends on the cost factors of interest rate, plant life, and consumable costs (mainly energy).

MEMBRANE

Electrodialysis (ED) is a membrane process based on the ability of semi-permeable membranes to pass select ions in a solution of ionized salts while blocking others. Thus, ions are removed from the water being treated leaving higher quality water.

The basic ED stack consists of an inlet feedwater channel, semi-permeable membranes, and two electrodes. Each electrode is connected to a source of direct current. The extent to which the feedwater is desalted depends on the residence time within the stack and the current density. A single electrodialysis stack can remove from 25 to 60 percent of entering total dissolved solids depending on feedwater characteristics. Further desalting requires that two or more stacks be used in series; these are referred to as stages. The actual selection of the number of stages required to treat a given water supply depends on its chemical composition and the desired product water quality.

With continued ED plant operation, fouling and scale deposits form on the membrane surfaces depending upon feedwater quality. The result is an increase in stack resistance and power requirements. Pretreatment of the feedwater and periodic cleaning of the membranes are therefore required. Polarity reversal (EDR) reduces scale problems in the ED process. It consists of periodically reversing the polarity and simultaneously interchanging the product and brine streams. Scale that has formed is loosened and carried off with the brine. EDR simplifies and reduces the cost of feed treatment.

The maximum life of ED membranes is generally considered to be 7 to 10 years. The energy required for ED is electricity for pumping of water and the transferring of ions. Approximately 3 kilowatt hours (kWhr) is required per 1,000 gallons (kgal) of product for each 1,000 ppm reduction in salinity of the feedwater to transfer the ions. An additional 3 kWhr per kgal is required for pumping.

The ED process generally offers potential economic advantage over other desalination processes for low TDS brackish water because the energy requirements of the ED process are proportional to the TDS removed. Also, since it operates at low temperature and pressure, there is very little corrosion.

Reverse osmosis (RO) operates on the following principle. When pressure in excess of the osmotic pressure is applied to a saline solution on one side of a semi-permeable membrane with a less saline solution on the other side of the membrane, pure water will flow through the membrane to the less saline solution but not the dissolved salts.

Two characteristics of an RO membrane are flux and salt rejection. Flux is the rate of production per unit area of membrane and depends on the membrane composition, the applied pressure, the operating temperature, and the membrane condition. Membranes are made with salt rejections of 90 to 95 percent for brackish water and over 98 percent for seawater. To overcome the osmotic pressure of the saline water and achieve a reasonable flux, an operating pressure of 250 psi or more is required for brackish water and over 800 psi for seawater.

At present, there are two predominant arrangements of membranes: the spiral wound and the hollow fine fiber. Spiral wound configurations use membranes in sheet or film form. The membrane material may be cellulose acetate or a composite material. Hollow fine fiber configurations use membranes in tubular form. Material may be aromatic polyamide or a blend of cellulose acetates.

Recovery in an RO system is the percentage of the feedwater quantity that is produced as product water. The higher the recovery, the greater the conversion of saline water into freshwater. Limitations on recovery are governed by the salinity of the feedwater, the flux of the membranes, the operating pressure, and the required flow rates in various portions of the membrane assemblies. The recovery is normally increased by adding cascading stages to the system. For brackish water, one stage will usually yield a recovery of 45 to 55 percent. This can be increased as much as 85 to 90 percent using multiple staging. For a seawater system, the recovery is generally in the area of 20 to 35 percent.

The capital and operating cost of the basic RO system will be increased by designing for higher recoveries but, at the same time, the cost of the feedwater supply, feed pretreatment, and brine disposal will be reduced. Consequently, an economic analysis during the design is desirable to determine the optimum recovery for the system.

It is essential that adequate consideration be given to the pretreatment requirements for RO membranes to prevent membrane fouling. Foulants are classified as either scales, metal oxides, particulates, colloids, or biologics. Scaling is most often caused by the precipitation of calcium carbonate and calcium sulfate salts.

This may be prevented by limiting the conversion, or recovery, so that these ionic species do not exceed their solubility limits. However, this is usually not practical. Feed treatment for scale control includes addition of acid for bicarbonate reduction to carbon dioxide and the addition of polyphosphate to sequester sulphate salt precipitation. Biological fouling is usually prevented by chlorination of the feedwater; however, dechlorination is then required for polyamide membranes.

In general, surface waters require extensive pretreatment while well waters require minimum feed treatment. For brackish water from most wells in South Florida, it is generally necessary to add only acid and a sequesterant followed by micron filtration if the wells are properly designed and the correct materials are used in the feedwater supply system.

The membrane feed pumping requirements comprise the largest percentage of the total process energy requirements in RO systems. The specific electrical consumption depends on the system recovery and the required membrane operating pressure. These are largely a function of the feedwater quality. The specific electrical consumption, therefore, increases as the feedwater TDS increases.

The main advantages of RO are reduced corrosion, low energy requirements, and low capital costs. The process also removes non-electrolytes such as organic compounds dissolved in the water.

ENERGY REQUIREMENTS

The following table presents the specific energy requirements for each process.

Process	Energy Requirements
Multi-Stage Flash	833 Btu/gal plus 6 to 10 kWhr/kgal
Multiple Effect	694 Btu/gal plus 4 to 6 kWhr/kgal
Vapor Compression (Diesel)	400 Btu/gal
Vapor Compression (Electric)	64 kWhr/kgal
Electrodialysis	6 to 12 kWhr/kgal
Seawater RO	28 to 40 kWhr/kgal
Brackish Water RO	3 to 6 kWhr/kgal

By necessity, the above table uses different units. The table below presents the energy requirements in terms of cost.

Process	Cost $/kgal
Multi-Stage Flash	2.55
Multiple Effect	2.06
Vapor Compression (Diesel)	2.20
Vapor Compression (Electric)	3.20
Electrodialysis	1.40 (W/Energy Recovery)
Seawater RO	0.45
Brackish Water RO	0.25

Review of the above table shows the inherently high energy costs for the distillation processes. The multi-stage flash (MSF) and multiple effect (MED) energy costs can be lowered approximately 30 percent by combining with a power plant; however, these costs are still in excess of the RO costs for the desalination of seawater.

The energy required by membrane plants will vary directly with the feed salinity (TDS). Figures 9 and 10 graphically show these variations for ED and RO.

ADVANCES IN THE STATE-OF-THE-ART

There are a number of small improvements in the distillation processes currently available, and soon to become available, that will give incremental economic savings in seawater desalination. These generally center around the type and arrangement of heat transfer surface used in the systems. None seem to offer significant savings in capital or operating costs.

The most significant advancement in membrane plants has been the development of low pressure RO membranes for brackish water. The use of these membranes will reduce the total unit production costs of brackish water RO plants by 15 to 20 percent. It is anticipated that further developments in membrane technology will lead to membranes with improved flux and salt rejection in the future.

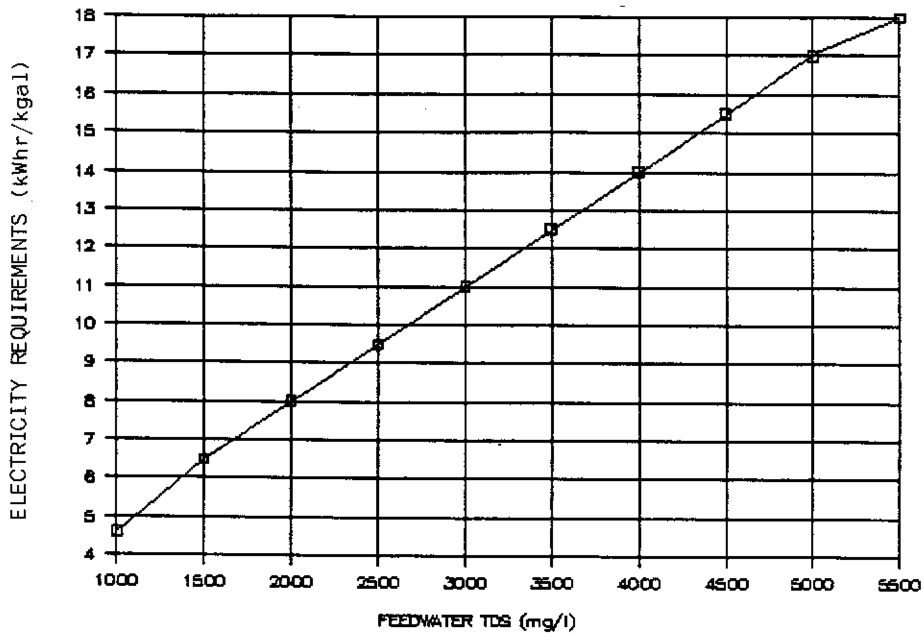

FIGURE 9. Electrodialysis Process, Energy Requirements

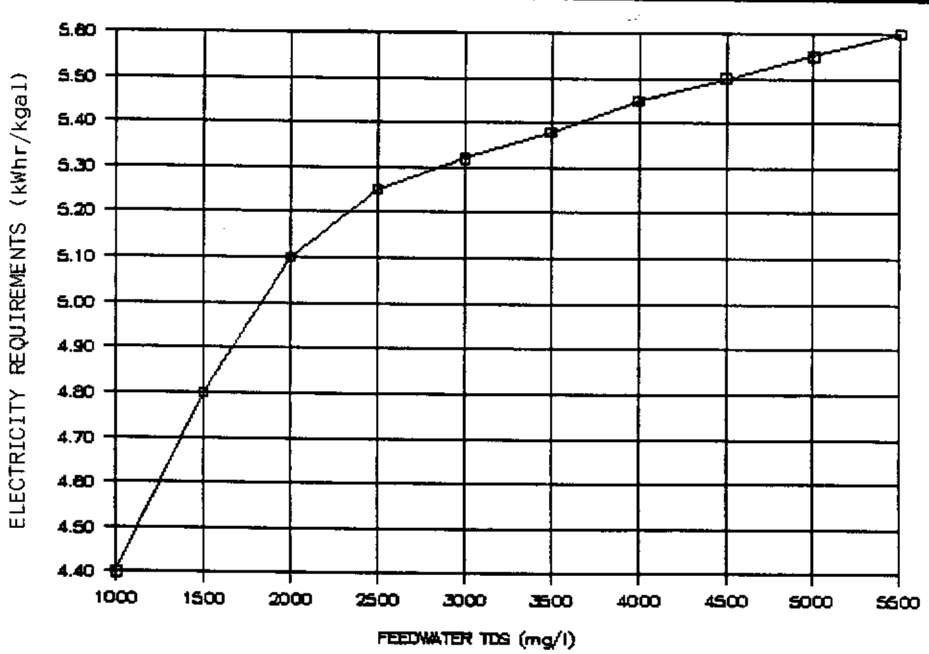

FIGURE 10. Reverse Osmosis Process, Energy Requirements

COSTS

Capital costs used in this discussion are based on construction in South Florida during 1986. These costs include both direct and indirect costs, architectural and engineering fees, and a contingency of 10 percent. Operating costs are based on 1986 costs of labor and consumables in South Florida with energy at $0.05/kWhr for electricity and $20.00/bbl for fuel oil.

For operating cost calculations, an 85 percent load factor is used in all cases and a 20-year life at 8 percent interest.

DESALINATION

Figure 11 presents the generalized unit capital costs for various desalination processes and plant sizes. Figure 12 gives the corresponding unit production costs and Figure 13, the total cost of water.

CONVENTIONAL WATER TREATMENT

For purposes of comparison, unit costs of treating surface and groundwater for potable water supplies in South Florida are provided in Figure 14. These were generally determined on the same basis of the estimates made for desalination systems but include treatment required to meet trihalomethane regulation.

A survey of unit costs for treating brackish water of 2,000 to 5,000 ppm TDS by RO is also given in Figure 14. This shows that the water produced by RO from brackish water should be less costly than conventionally treated water in plant sizes less than 3 mgd and closely competitive up to a plant size of 12 mgd. The costs for each water treatment scheme assumes that the water to be treated is available near the plant site.

CONCLUSIONS

As evidenced in the data presented in this discussion, it appears that water demands can be expected to be met in South Florida using current supplies through the year 2000. Intelligent planning is

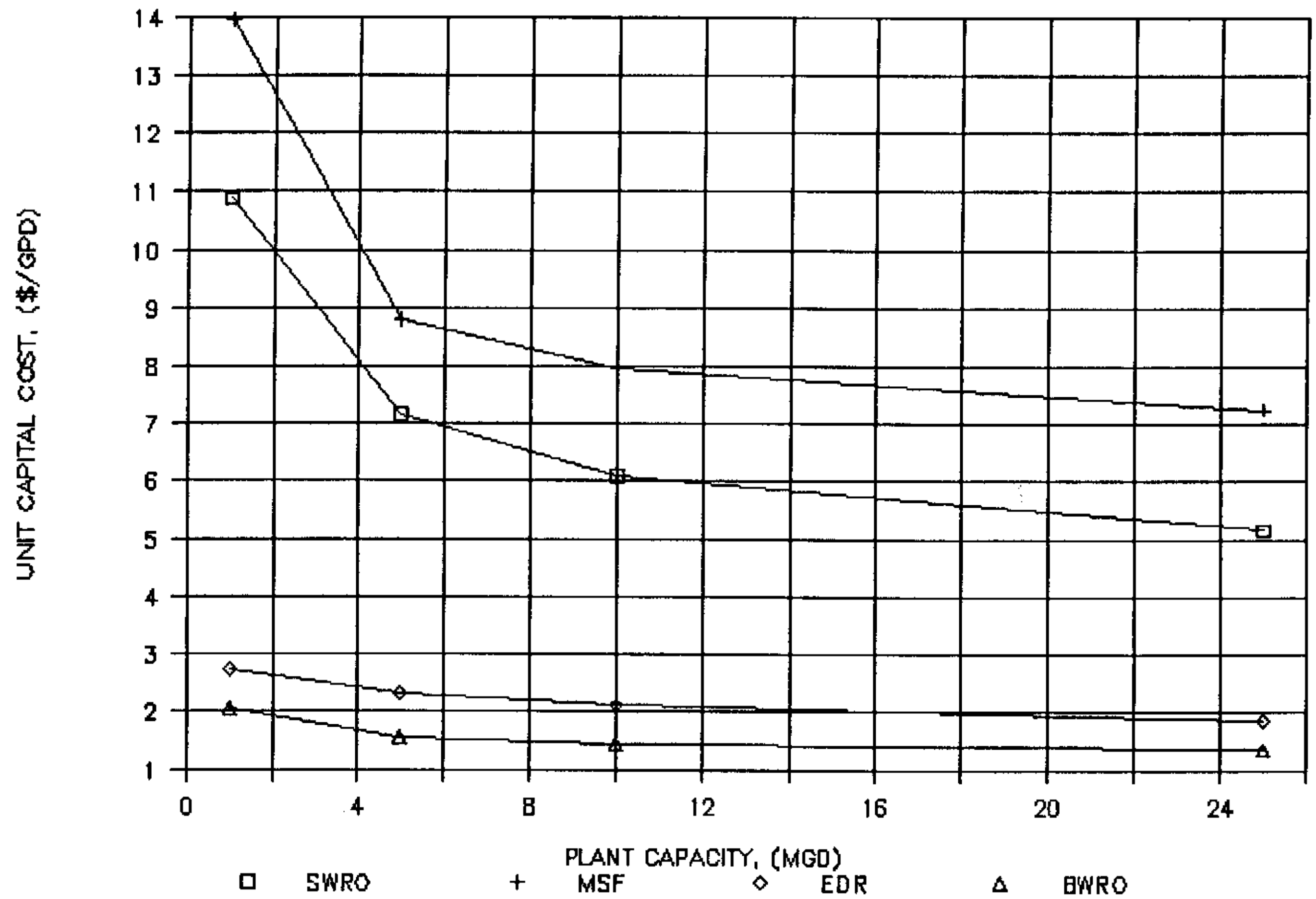

FIGURE 11. Unit Capital Costs, Desalination Processes

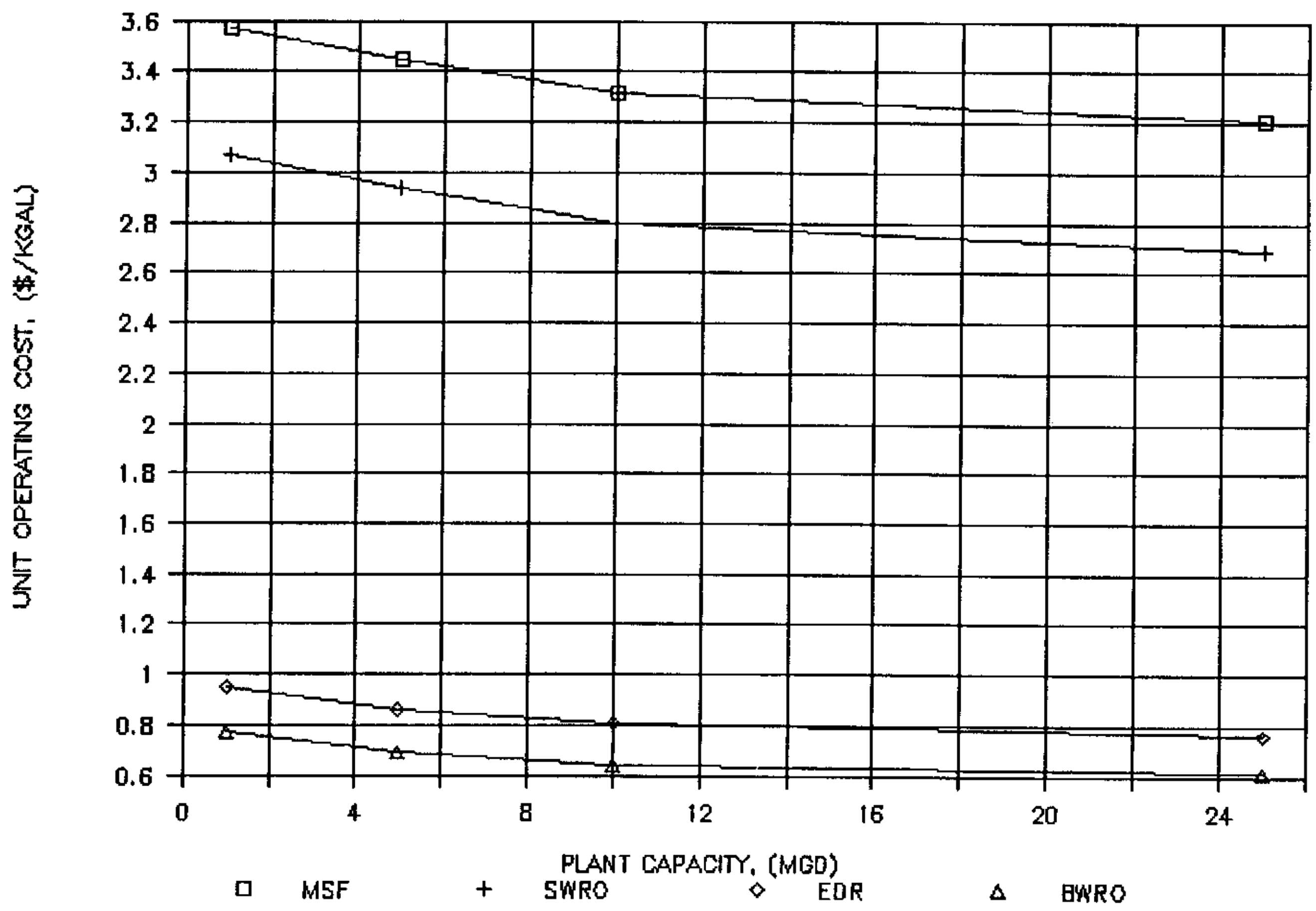

FIGURE 12. Unit Operating Costs, Desalination Processes

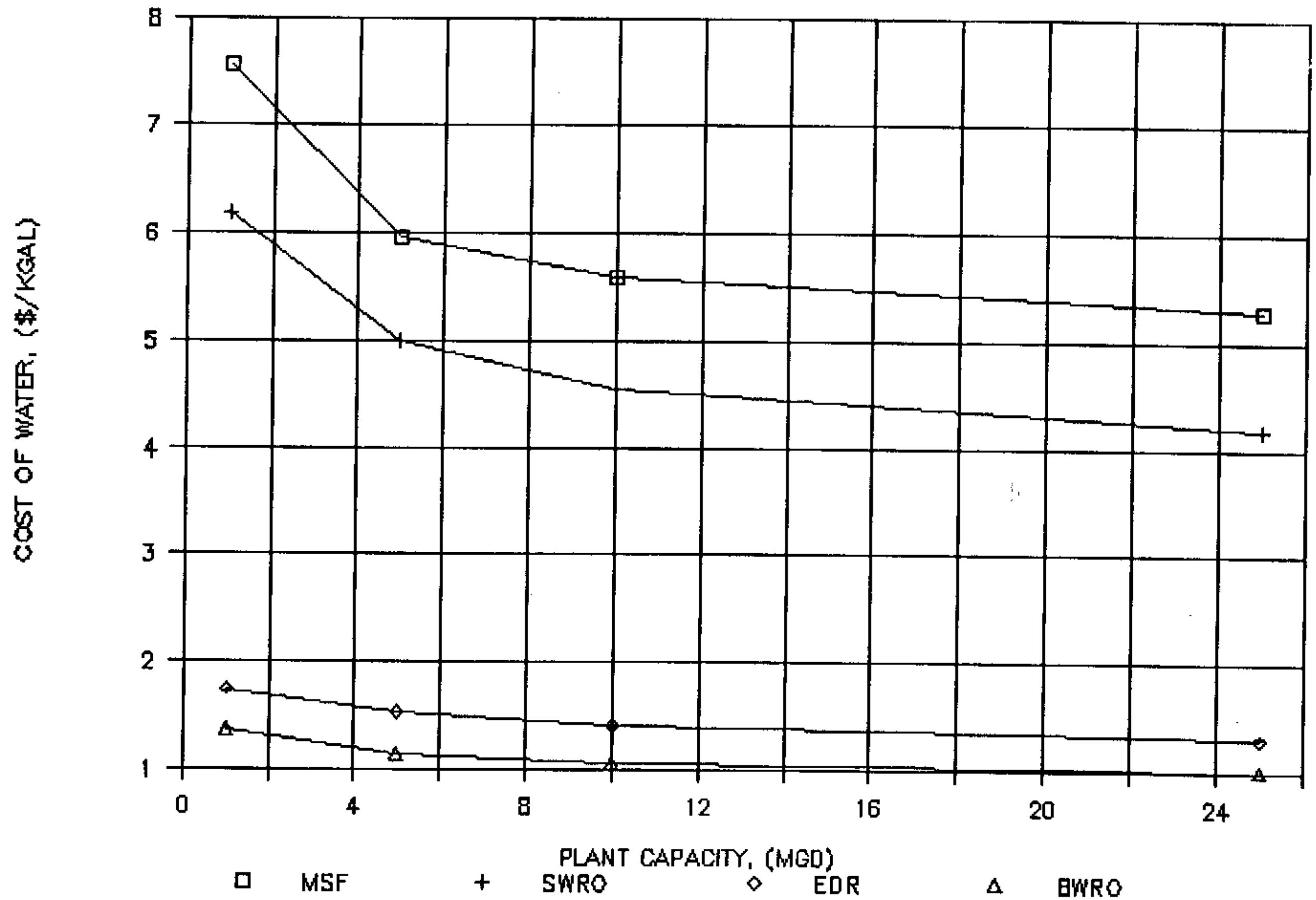

FIGURE 13. Cost of Water, Desalination Processes

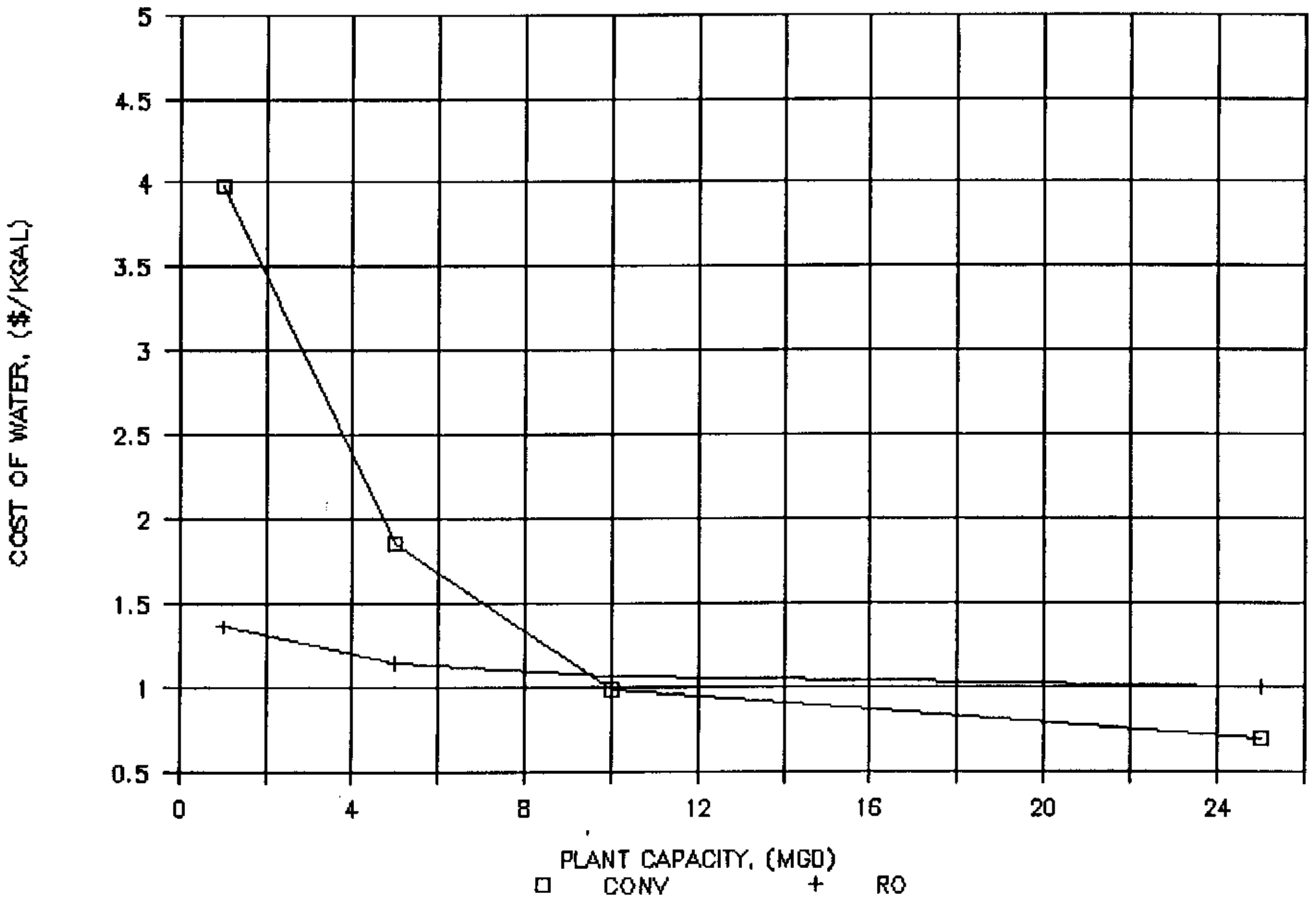

FIGURE 14. Water Treatment Costs

required now to provide water beyond 2000. Desalination can, and should, play an important role in meeting projected demands.

Of the desalination processes currently available, membrane types offer the most economic advantages in the treatment of drinking water because of their low energy consumption. In fact, in the treatment of brackish water, RO can now effectively compete with conventional lime softening. As membranes continue to develop, further reductions in energy requirements are expected for RO, making it even more economically attractive.

AN INTRODUCTION TO DESALTING IN FLORIDA

by

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DESALINATION IN SOUTH FLORIDA
August 21, 1987

AN INTRODUCTION TO DESALTING IN FLORIDA

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Desalting as a water treatment process is beginning to play an increasingly significant role in the development of water resources in the State of Florida. The term desalting refers to the removal of dissolved salts from water; the process is also called desalination or desalinization. Over a hundred desalting plants are currently operating in Florida, producing a total capacity in excess of 40 million gallons per day (mgd). This volume is steadily increasing as new plants are planned and placed online. The major applications for desalting technologies in Florida are the production of potable water for municipal purposes, production of ultrapure water for industrial purposes, and the concentration of brines.

PROCESS OVERVIEW

Desalting renders waters usable that were naturally unsuitable for potable consumption because of their dissolved salt content. In Florida, ample supplies of both seawater and brackish water are available near many major population centers.

The incoming stream is the feedwater which is saline and is obviously central to the process; without a source of saline water, a desalting process cannot be applied. The output streams are freshwater which is the desired product and the brine which carries off the excess salts that were removed from the saline feedwater. In the past, the disposal of this brine (also referred to as reject or concentrate) was often a minor concern, but current regulations and public awareness make it essential to dispose of the brine in a manner that is environmentally appropriate and meets regulatory standards.

The method of brine disposal can be a key element in whether a desalting process can be economically utilized in a given situation.

The cost component, as will be discussed later, is very site-specific and depends on many factors, including the type and source of saline water, the level of dissolved salts desired in the freshwater produced, and the method of brine disposal.

HISTORY OF USAGE

Florida has often been a testing ground for desalting, both on a national and international basis. The existence of readily exploited sources of seawater and brackish water, the intense drive to develop water-short areas in the state, the willingness on the part of the consumer to pay the cost of the water produced by desalting, and the readiness of the state's water industry to try new treatment processes created a favorable technological climate for desalting process testing in Florida.

In the past 30 years, all of the major desalting processes have been tried in Florida, including distillation, solar humidification, membrane distillation, electrodialysis, and reverse osmosis.

DISTILLATION

One of the first major municipal seawater distillation plants in the United States was installed in the Florida Keys around 1967. This 2.5-mgd multistage flash plant supplied water to the Key West area for approximately 15 years, after which it was scrapped. During its operating life, the plant had required extensive repairs caused by corrosion and other problems. Since then, the major application for the distillation process in Florida has been for brine concentration. An example of this is a large vapor compression distillation plant located in Gainesville.

SOLAR HUMIDIFICATION

A number of research projects have been performed in Florida on the use of solar energy to desalt saline water. The most extensive was the testing carried out in Daytona Beach under a grant from the Federal Office of Saline Water (OSW) in the late 1960's.

MEMBRANE DISTILLATION

During the early 1980's, a private firm installed several test units and a factory in Florida to utilize and produce membrane distillation units. The company subsequently withdrew from the market.

ELECTRODIALYSIS

Florida has been the site of two major electrodialysis facilities: one at Siesta Key and the other on Sanibel Island. The Siesta Key plant was installed about 1970 and had a capacity of approximately 2 mgd. Shortly thereafter, a 2.5-mgd plant was built on Sanibel Island. At the time, both plants were world class facilities in terms of capacity, as few other brackish water plants exceeded 1 mgd. The Siesta Key plant was closed after a few years when a less costly source of water was obtained from the mainland. The Sanibel Island plant is still operating.

REVERSE OSMOSIS

Much of the initial work that led to the commercial development of the reverse osmosis process was undertaken at the University of Florida in the mid-1950's by Professor Charles Reid. One of the first successful commercial reverse osmosis installations in the state was the 0.5-mgd plant at Rotunda West, which was built in 1972 and is still in operation. It was followed by a number of other installations and in 1977, a 3-mgd plant was built at Cape Coral. Both plants were, at the time of their construction, ranked among the largest of their kind in the world. Since then, over a hundred reverse osmosis plants have been installed in the state and the Cape Coral plant has been expanded a number of times.

CURRENT USAGE

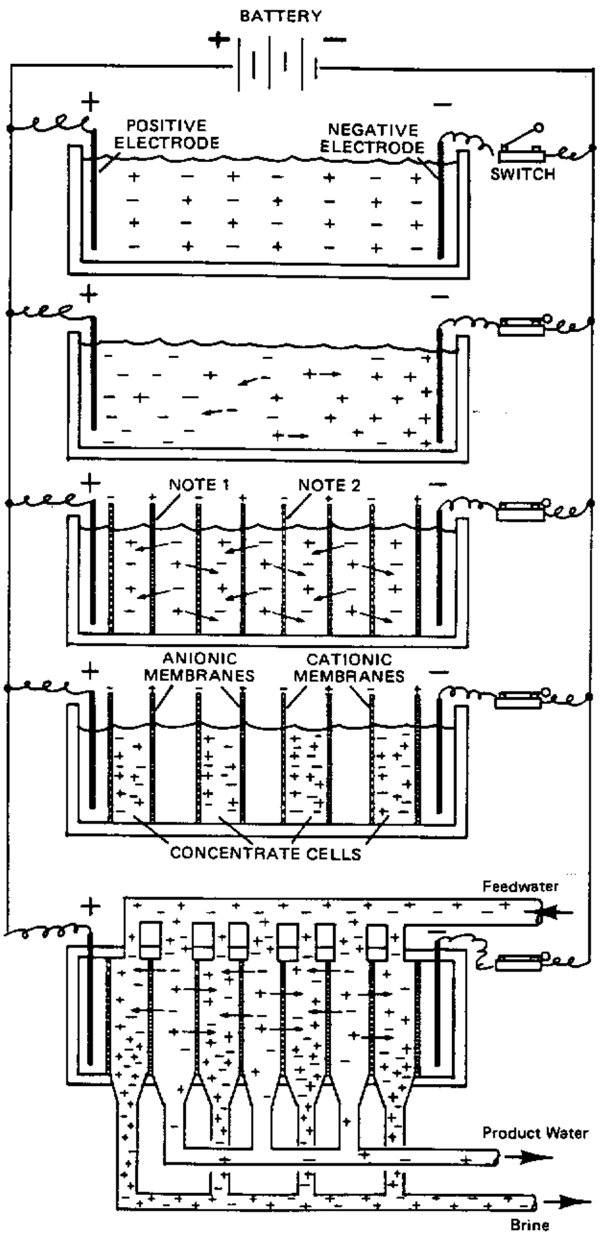
Electrodialysis and reverse osmosis are the processes that have proven, so far, to be the best suited for desalting brackish water in Florida. The remainder of this discussion outlines the basics of these two processes.

ELECTRODIALYSIS

Electrodialysis is founded on the principle that salts dissolved in water are ionic in nature. Typical ions are sodium, chlorides, sulfates, and carbonates. Each has an electrical charge and can be attracted to an electrical pole of opposite charge. Figure 1 illustrates how ions are removed in the electrodialysis process.

The entering saline feedwater passes in a narrow channel between two membranes. On the outside of these membranes are two oppositely charged plates (electrodes). The physical characteristics of the membranes allows them to pass ions, but not water. In addition, the membranes are constructed to either permit negative or positive ions to pass through. Both types of membranes are used in an electrodialysis unit. The anionic membranes pass anions (negatively charged ions) and resist the passage of cations (positively charged ions) and the cationic membranes do the opposite.

As shown in Figure 1, the different membranes are placed alternately (anionic, cationic, anionic, etc.) to form several channels. As the saline water flows through the channel, the ions in the water are attracted to the charged electrodes and pass through the appropriately constructed membranes. The ions enter the adjacent channel and are trapped because the next membrane has opposite membrane passing characteristics that will not permit further passage of the ions toward the electrodes. The adjacent channels, referred to as brine channels, collect the ionic salts as they leave the saline feedwater. A flow is maintained through the brine channels to flush out the unwanted salts, and this concentrated solution makes up the brine stream.



Many of the substances which make up the total dissolved solids in brackish water are strong electrolytes. When dissolved in water they ionize; that is, the compounds dissociate into ions which carry an electric charge. Typical of the ions in brackish water are Cl^{-1}, Na^{+1}, HCO_3^{-1}, Mg^{+2}, SO_4^{-2}, and Ca^{+2}. These ions tend to attract the dipolar water molecules and to be diffused in times, fairly evenly throughout a solution.

If two electrodes are placed in a solution of ions, and energized by a battery or other direct current source, the current is carried through the solution by the charged particles and the ions tend to migrate to the electrode of the opposite charge.

If alternately fixed charged membranes (which are selectively permeable to ions of the opposite charge) are placed in the path of the migrating ions, the ions will be trapped between the alternate cells formed.

Note 1: A positively fixed charge (anionic) membrane will allow negative ions to pass, but will repel positive ions.

Note 2: A negatively fixed charge (cationic) membrane will allow positive ions to pass, but will repel negative ions.

If this continued, almost all the ions would become trapped in the alternate cells (concentrate cells). The other cells, which lack ions, would have a lower level of dissolved constituents and would have a high resistance to current flow.

The phenomenon illustrated above is used in electrodialysis to remove ions from incoming saline water on a continuous basis. Feedwater enters both the concentrate and product cells. Up to about half of the ions in the product cells migrate and are trapped in the concentrate cells. Two streams emerge from the device: one of concentrated brine and the other with a much lower concentration of TDS (product water).

This figure is adapted from *The U.S.A.I.D. Desalination Manual* (Buros, et. al, 1980) and is used courtesy of the U.S. Agency for International Development.

FIGURE 1 Movement of Ions in the Electrodialysis Process

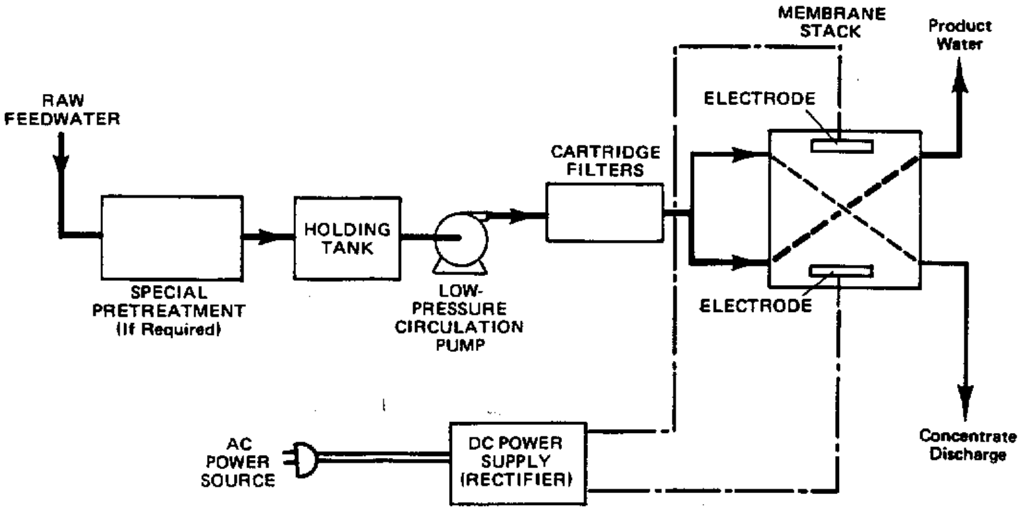
The feedwater loses most of its ionic constituents as it flows through the unit and becomes the freshwater stream. The passage between the electrodes will generally reduce the ionic concentration by about 50 percent. If further salt reduction is required, then the feedwater is passed through a second or third set of channels and electrodes (called stages). Electrodialysis can generally have a high recovery rate; that is, the ratio of freshwater recovered for each unit of feedwater can be high, often in the range of 80 to 90 percent.

Figure 2 shows a simplied schematic of a typical electrodialysis unit. Some type of pretreatment (usually filtration and occasionally chemical addition) is required to prevent the feedwater from damaging the membranes. The pretreated feedwater then passes through the electrodialysis stages. The product water (freshwater) undergoes post-treatment (e.g., degassification or pH adjustment) and is then disinfected and used in the potable water system. The water flows through the unit with a pressure of less than 50 pounds per square inch (psi). The main energy requirement is the electricity required to operate the rectifier, which maintains the electrical charge on the electrodes. This energy usage is in direct proportion to the amount of salts removed.

One process innovation that was introduced into the industry about 1970 was the use of a reversal cycle in the operating schedule of the electrodialysis unit. At set intervals, the polarity of the electrodes in the unit is reversed and the feedwater channel becomes the brine and vice versa. This innovation, which is marketed under the name electrodialysis reversal (EDR), minimizes the need for pretreatment chemicals and reduces the problem of scaling inside the membrane stack.

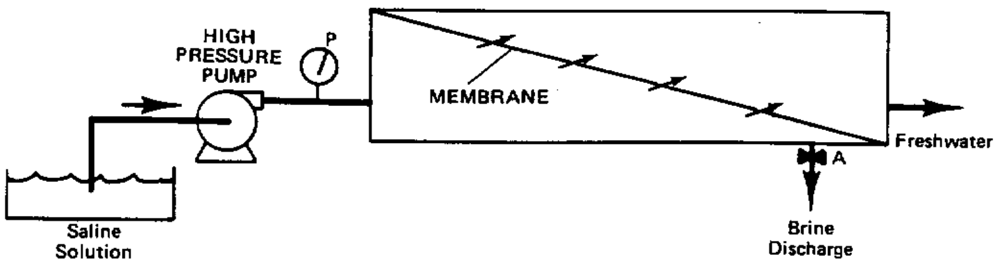
REVERSE OSMOSIS

Electrodialysis desalts water by allowing the salts, but not the water, to pass through a membrane; reverse osmosis operates almost directly opposite. In this process, the saline feedwater is placed in a chamber and pressurized against a membrane as shown in Figure 3.



This figure is adapted from *The U.S.A.I.D. Desalination Manual* (Buros, et. al, 1980) and is used courtesy of the U.S. Agency for International Development.

FIGURE 2 Basic Components of an Electrodialysis Unit



A membrane assembly is generally symbolized as a rectangular box with a diagonal line across it representing the membrane.

This figure is adapted from *The U.S.A.I.D. Desalination Manual* (Buros, et. al, 1980) and is used courtesy of the U.S. Agency for International Development.

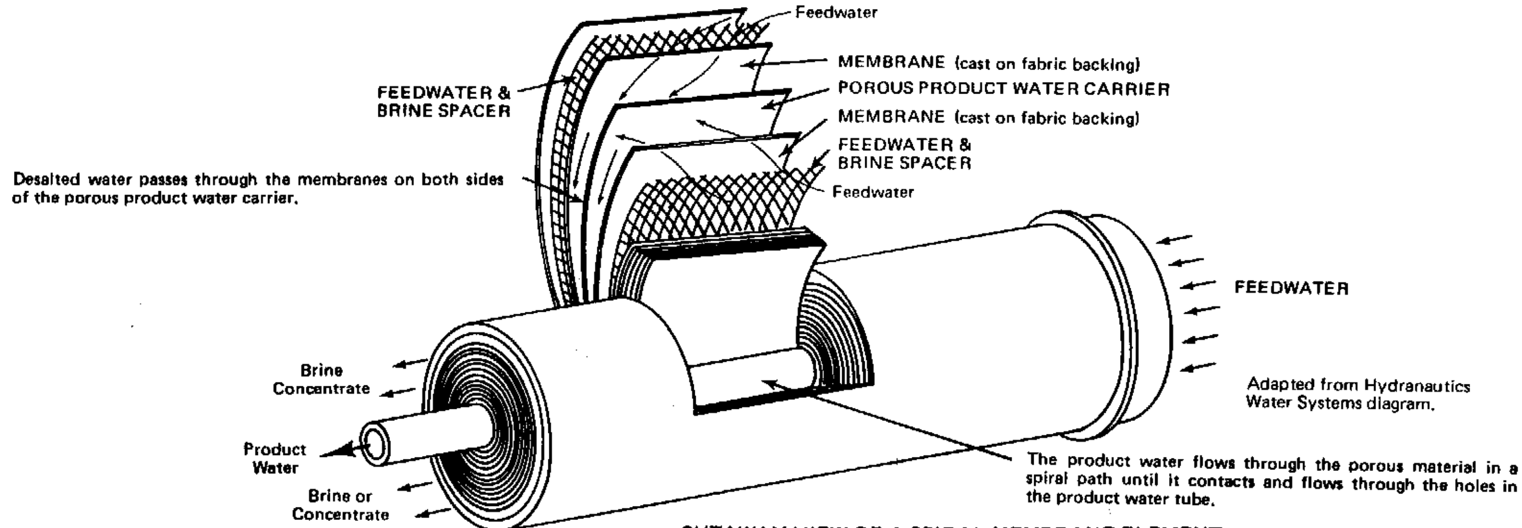
FIGURE 3 Elements of a Reverse Osmosis System

The membrane is considerably thinner than those used for electrodialysis and is semi-permeable. When subjected to pressurized saline water, the membrane will allow freshwater to pass through while rejecting the passage of dissolved salts. The remaining feedwater becomes increasingly saline as the salts are concentrated in a decreased volume of water. This highly saline water is discharged as the brine, or concentrate, stream.

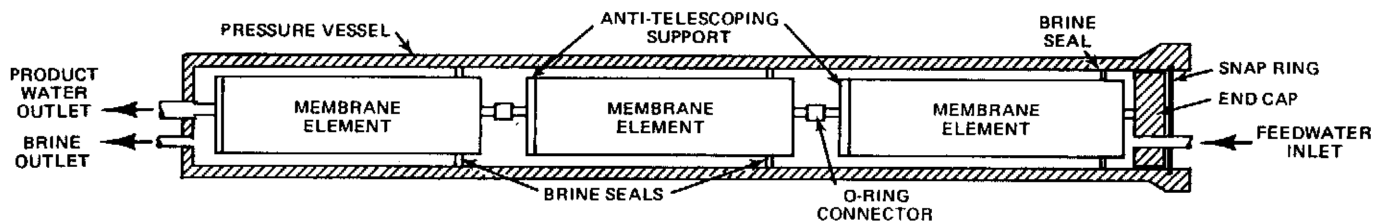
The key component in this process is the membrane. It must be thin and suitably supported to minimize resistance to the passage of freshwater, but strong enough to sustain the pressure without being ruptured. At the same time, the membrane has to have the physical and chemical characteristics to reject salts and resist chemical and biological degradation from substances in the feedwater. In the early days of desalting, these pressures ranged up to 600 psi for brackish water membranes and twice that for seawater.

Several membrane types and configurations were tried in an effort to find a commercially viable product. The most common types were the plate and frame, tubular, hollow fine fiber, and spiral wound. Those proven most commercially successful for producing potable water for municipal purposes have been the spiral wound and hollow fine fiber membranes, illustrated in Figures 4 and 5.

Figure 6 shows a simplified schematic of a typical reverse osmosis unit. The incoming feedwater requires some type of pretreatment (chemical addition and filtration) to prevent it from damaging the membranes. The pretreated feedwater is then pressurized in the vessel containing the membrane. The process is arranged in stages, each of which consists of a single pass of the product water through a membrane. Up to about 50 percent of the feedwater can be recovered as fresh product water in each stage. To increase the percentage of feedwater recovered as product water, a number of stages are arranged in series. In Florida, two stages are most common, but there are some plants with as many as three. Each stage uses the brine stream from the preceding stage as its feedwater source. Plants in Florida typically have recoveries ranging from 50 to 75 percent.



CUTAWAY VIEW OF A SPIRAL MEMBRANE ELEMENT



CROSS SECTION OF PRESSURE VESSEL WITH 3-MEMBRANE ELEMENT

This figure is adapted from *The U.S.A.I.D. Desalination Manual* (Buros, et. al, 1980) and is used courtesy of the U.S. Agency for International Development.

FIGURE 4 Spiral Membrane Cut-Away View with Elements in a Pressure Vessel

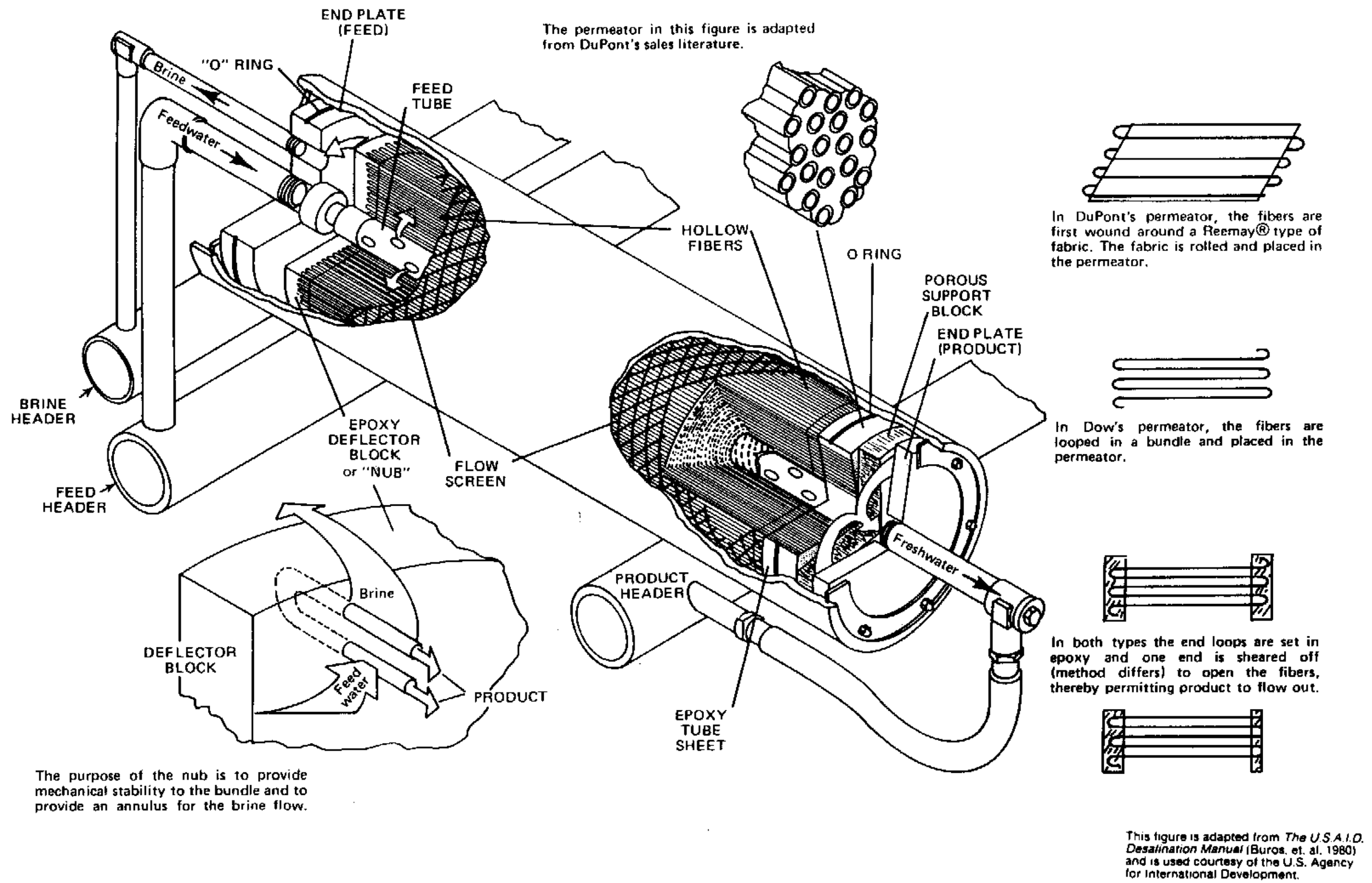
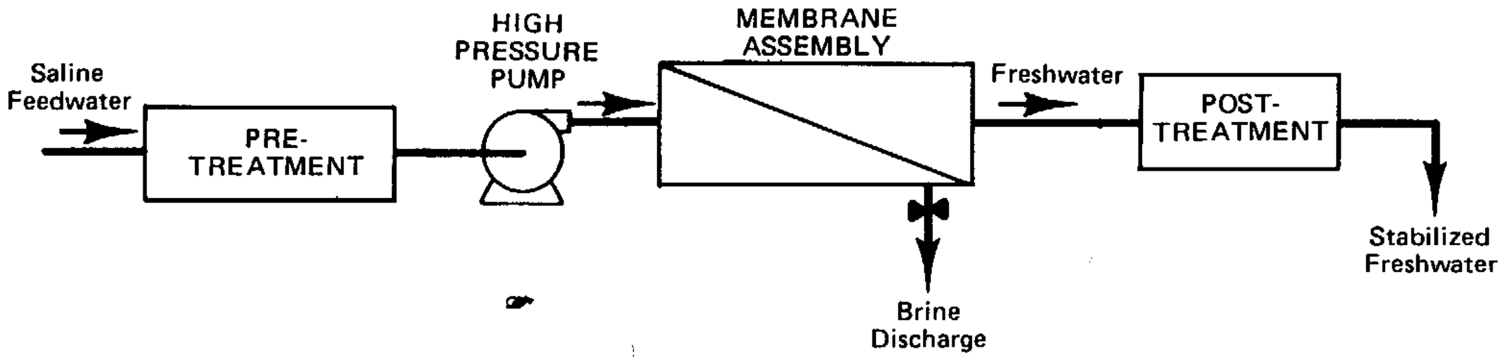


FIGURE 5 Permeator Assembly for Hollow Fine Fiber Membranes



This figure is adapted from *The U.S.A.I.D. Desalination Manual* (Buros, et. al, 1980) and is used courtesy of the U.S. Agency for International Development.

FIGURE 6 Flow Diagram of a Reverse Osmosis System

After passing through the membrane, the product (fresh) water is usually post-treated by degassification and pH adjustment, and is then disinfected and used in the potable water system. To desalt brackish water, the feedwater must be pressurized to about 250 to 500 psi, depending on the salinity, membrane, etc. The water passing through the membrane loses all its pressure, but the brine stream leaves the pressure vessel at about 20 to 40 psi less than the pressure exerted against the membrane. In a few plants in Florida, this potential energy is recovered by using the pressurized brine stream to operate a turbine or other mechanical device. The main energy usage in a reverse osmosis plant is for pressurizing the feedwater, so energy recovery devices can be a valuable method of reducing operating costs.

OPERATIONAL CONSIDERATIONS

As illustrated in Figures 2 and 6, the basic unit operations of both electrodialysis and reverse osmosis are quite similar. An important difference is that, with electrodialysis, the salts pass through the membranes and leave freshwater behind, while with reverse osmosis, the freshwater passes through the membranes and leaves the salts behind.

Both processes require a pretreated feedwater to protect the membrane from physical damage by solid materials that might be suspended in the water. The formation of scale on the surface of the membrane is also a shared problem. Scaling tends to occur when the concentration of dissolved salts in the feedwater adjacent to the membrane increases as the desalting process takes place. If allowed to progress too far, the concentration of certain constituents can exceed their saturation level and the constituent can begin to precipitate. Harmful effects can occur if scale covers the membrane surfaces and severely reduces the effectiveness of the desalting unit.

Energy is a major cost factor for both processes, although it is used for different purposes. With electrodialysis, electricity powers a rectifier; with reverse osmosis, it is used for the high pressure pump. Energy usage varies depending on the application, but is usually in the range of 6 to 12 kilowatt hours per 1,000 gallons (kWh/kgal) of product.

Because the total costs of desalting are affected by a variety of site-specific factors, no single cost is applicable. In obtaining cost data, it is very important to delineate the items included. Serious misunderstandings can arise about the true cost for a locality if the cost data neglect to include some of the actual costs. For example, significant cost could be incurred for brine disposal, especially for plants located further away from the saline coastal surface waters. A helpful guide for determining what costs are included is the worksheet in Figure 7.

With any desalting plant, a key factor for ultimate success is a good operations staff. Both processes require day-to-day operational decisions that are critical to the long-term, cost-effective operation of the facility.

CONCLUSIONS

Florida has had an important role for over 30 years in the development and use of desalination technologies. Much of this experience has provided the desalination industry with information and background that it has used to improve the various processes.

Currently in Florida, more than 100 desalination plants are in operation, with over 40 mgd in installed capacity. The reverse osmosis process is more commonly used, but there are a number of electrodialysis plants in the state. The overall experience to date has generally been very positive and has shown that desalting can be an effective and reliable method to increase the water resources in Florida by making saline waters a source of potable water in many locations.

REFERENCES

Buros, O. K., et al. 1980. The U.S.A.I.D. Desalination Manual. Published by CH2M HILL International for the U.S. Agency for International Development.

DESALINATION COST SUMMARY SHEET

Location ____________ Capacity ______ mgd [m³/d]
Type of Plant ____________ Plant Life ______ Years Plant Factor ______
Source of Feedwater ____________ TDS Level ______
Recovery or Performance Factor ____________
Energy Source(s): Fuel (______ type)/Electricity/Steam (Circle Sources)

CAPITAL COSTS

DIRECT CAPITAL COSTS

1. Feedwater Supply Development $______
2. Feedwater Treatment $______
3. Desalination Equipment $______
4. Site Development $______
5. Energy Source Development $______
6. Electrical Equipment (switchgear) $______
7. Brine Disposal $______
8. Product Water Storage and Treatment $______
9. Other $______

SUBTOTAL DIRECT CAPITAL COSTS (1-9) $______ (A)

INDIRECT CAPITAL COSTS

10. Interest During Construction $______
11. A/E, Project Management Fees $______
12. Contingencies $______
13. Startup Costs $______
14. Other $______

SUBTOTAL INDIRECT CAPITAL COSTS (10-14) $______ (B)

TOTAL DEPRECIABLE CAPITAL COSTS (A + B) → $______ (C)

OTHER CAPITAL COSTS (NON-DEPRECIABLE)

15. Land ______ acres (m²) $______
16. Working Capital $______

TOTAL OF OTHER CAPITAL COSTS (15-16) → $______ (D)

TOTAL OF ALL CAPITAL COSTS (C + D) → $______

UNIT CAPITAL COST ($/GPD [m³/d] INSTALLED CAPACITY) → $______ /gpd [m³/d]

ANNUAL COSTS

Recurring Costs

17. Taxes $______
18. Insurance $______
19. Other $______

TOTAL ANNUAL RECURRING COSTS (17-19) → $______ (E)

OPERATION & MAINTENANCE (O&M) COSTS

20. Labor—Salaries $______
21. Labor—General & Administrative Overhead (______%) $______
22. Chemicals $______
23. Supplies and Maintenance Materials $______
24. Membrane Replacement (______ yr Life) $______
25. Special Repairs or Overhauls $______
26. Energy—Fuel/Steam (Circle one) cost/unit ______ $______
27. Energy—Electricity ______ $/kWhr $______
28. Other $______

TOTAL ANNUAL O&M COSTS (20-28) → $______ (F)

ANNUAL FIXED CHARGE

______% Interest & ______ yr Plant Life   Capital Recovery Factor (CRF) ______

$$\left(\frac{\$\_\_\_\_\_\_}{\text{(Depreciable Capital)}}\ (C) \times \frac{\_\_\_\_\_\_}{\text{(CRF)}}\right) + \left(\frac{\_\_\_\_\_\_}{\text{(Nondepreciable)}}\ (D) \times \frac{\_\_\_\_\_\_}{\text{(CRF)}}\right)^{*} = \$\_\_\_\_\_\_\ (G)$$

TOTAL ANNUAL COSTS (E + F + G) → $______ (H)

*In many analysis the capital recovery is not computed for nondepreciable capital (D).

UNIT PRODUCTION COSTS

Annual Production ______ kgal [m³] ☐ Design ☐ Actual

Operating Units

$$\text{UNIT COST} = \frac{\text{Total Annual Cost (H)}}{\text{Actual Annual Production}} = \_\_\_\_\_\_ = \$\_\_\_\_\_\_ \text{/kgal [m}^3\text{]}$$

For Estimating Costs

$$\text{UNIT COST} = \frac{\text{Total Annual Cost (H)}}{\text{Annual Design Capacity} \times \text{Plant Factor}} = \_\_\_\_\_\_ = \$\_\_\_\_\_\_ \text{/kgal [m}^3\text{]}$$

Cost Estimator ____________ Date ______ Project ______

Attach the Desalination Project Information Sheets

FIGURE 7 Desalination Cost Summary Sheet

This figure is adapted from *The U.S.A.I.D. Desalination Manual* (Buros, et. al. 1980) and is used courtesy of the U.S. Agency for International Development.

BASICS OF ELECTRODIALYSIS

by

Linda Ruth Schmauss
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Watertown, Massachusetts

DESALINATION IN SOUTH FLORIDA
August 21, 1987

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INTRODUCTION

Electrodialysis (ED) was the first membrane process developed for desalting brackish water. Improvements in membrane properties and the economics of operation led to commercial development in the 1950's. Electrodialysis dominated the rapidly growing membrane desalting industry through the 1960's.

The early 1970's marked a major technological improvement in ED technology. Electrodialysis reversal (EDR) provided the desalting marketplace with a highly reliable process requiring minimal pretreatment or online chemical addition. Recovery ratios for membrane processes leaped from the 50 percent to 60 percent range to 80 percent to 90 percent recovery with electrodialysis reversal desalting.

Electrodialysis membrane desalting found its first application in potable water treatment. The commercial market quickly expanded to the industrial sector, providing process water and pretreatment to more cost-intensive demineralization processes. In recent years, EDR has found new application in a wide variety of waste treatment, brine concentration, and water recycle requirements of an effluent-conscious market.

Our needs for water treatment shift with newly recognized challenges to our health and environment. ED is an important and capable technique in water management which meets many specific needs in water use. The past and present challenges to water treatment include saltwater intrusion, nitrate contamination, fluoride control, selenium poisoning, and contamination by organics and heavy metals of our waters. The role of EDR in the strategies to meet these challenges is discussed. Operational data and detailed water analyses are presented.

PRINCIPLES OF ELECTRODIALYSIS

Electrodialysis is an electrochemical separation process in which salts that are dissolved in water are forced through ion selective membranes under the influence of an applied electric field. The net result of this dialytic process is the transfer of ions from a less concentrated solution to a more concentrated solution or brine.

Historically, electrodialysis was first demonstrated in a simple three-compartment cell. The compartments of this electrolytic cell were separated from each other by relatively non-selective ion-permeable membranes. The membranes themselves form the walls of the water tight compartments. The electrodes of this rudimentary electrolytic cell were housed in the end compartments. A saline solution was introduced to all three compartments of the cell. Direct electric current applied across this cell effected a measurable decrease in the initial salt concentration of the middle compartment due to the migration of cations and anions into the respective electrode compartments.

In 1940, Meyer & Strauss invented the multi-compartment electrodialysis cell with ion-selective membranes (see Figure 1). This multi-compartment ED cell was composed of a stack of alternately arranged cation-permeable cellophane membranes and anion-permeable membranes of artificial gut. The electrodes were located in the end compartments. Application of DC potential across this ED cell attracted the dissolved cations through the cation permeable membranes toward the negatively charged cathode. Anion migrated across the anion permeable membrane boundary toward the anode. Further movement of the negatively charged ions toward the anode was restricted by the cellophane membranes which were impermeable to anions. Similarly, cations were retained in the concentrating compartments by the cation impermeable gut membranes. The net result of this early multi-compartment ED cell experiment was electrolyte depletion in the ion transfer compartments alternating with salt enriched compartments.

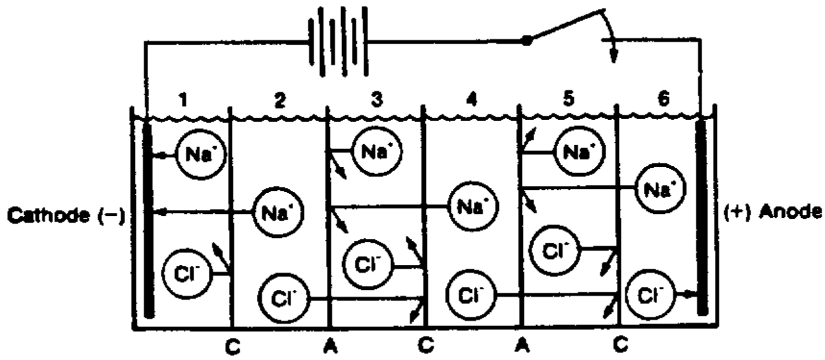

FIGURE 1
The Multi-Compartment ED Cell

Modern ED cells are basically the same as the experimental cell assembled by Meyer & Strauss in 1940. Improvements in membrane properties have insured the successful commercialization of the ED process. The membranes used in the 1940's had poor mechanical and chemical resistance properties. The high electrical resistance of these early membranes and the relatively low permselectivity limited the practical application of electrodialysis in industry.

Modern ion exchange membranes were developed in the 1950's. These membranes exhibited high ion selectivity with good mechanical strength and chemical stability. The electrical resistance of the membranes minimized the voltage drop across the cell and thus the overall power requirement of the ED system during the desalting process.

These improved membranes consist of synthetic ion exchange resin materials fabricated in sheet form. These membrane sheets are reinforced with a woven synthetic fiber cloth. Anion-selective membranes bear chemically bonded positively charged quaternary ammonium groups. The mobile, negatively-charged counter-anions are electrokinetically attracted to the fixed cation groups. The cation-selective membranes bear chemically-bound, negatively charged sulfonate anions. These fixed, negatively charged groups are loosely associated with mobile counter-cations. The counter-ions are the principal carriers of the applied electric current. Both the cation and anion membranes are impermeable to water under pressure.

The low electrical resistance of ED membranes is attributable to the high concentration of counter-ions. Ion-selectivity of these modern ion exchange membranes is related to the relatively high concentration of chemically bound sulfonate or quaternary ammonium groups. These fixed, charged chemical groups tend to exclude the mobile ions of like charge and pass oppositely charged ions.

The cation and anion selective membranes are separated from each other within the ED cell by polyethylene spacers. These spacers form channels or flowpaths across the membrane surfaces within the stack. The polyethylene spacers are designed to provide efficient, turbulent flow of the feedwater across the membrane surfaces.

The basic building block of an electrodialysis cell is called the cell pair and is illustrated in Figure 2. One ED cell pair consists of one cation membrane, one anion membrane, and two polyethylene flow spacers. Hundreds of cell pairs are assembled into a membrane stack. The electrodes are located at the top and bottom of the membrane stack and complete the electrodialysis cell.

DESIGN CONSIDERATIONS

Each ED system is designed to meet the specific needs of an application. The production capacity determines the size of the ED unit, pumps, piping, and stack. The required level of demineralization dictates the configuration or staging of the membrane stack.

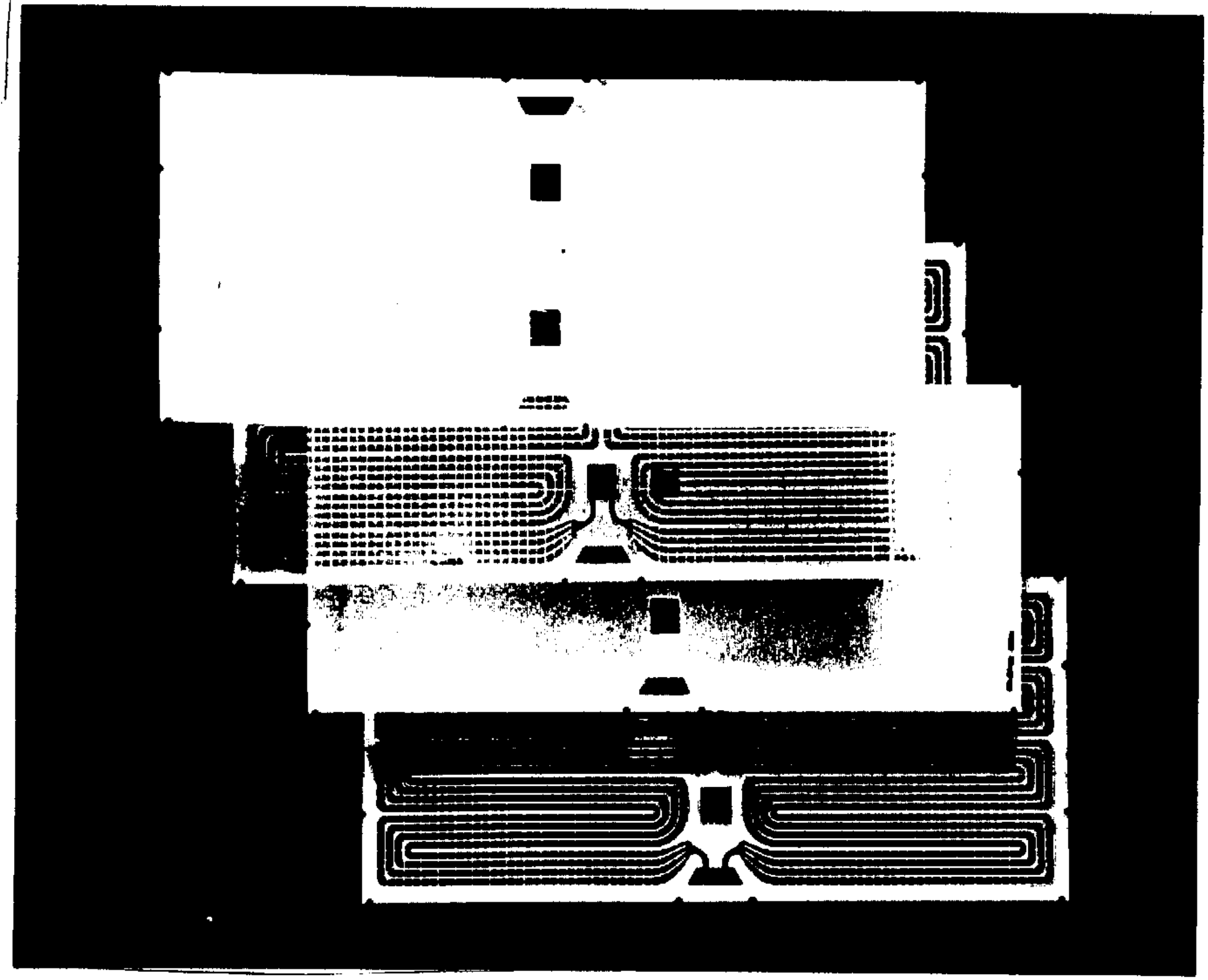

FIGURE 2 The Cell Pair

Membrane stack staging provides sufficient membrane area and retention time for the desired quantity of salt to be removed from the feedwater. There are two types of staging: hydraulic staging and electrical staging.

A single hydraulic stage normally provides 40 to 50 percent salt removal. If a greater level of demineralization is required, additional hydraulic stages in series are employed. Thus, a two hydraulic stage plant yields 65 to 75 percent salt removal, a three hydraulic stage plant yields 82 to 88 percent salt removal and so on.

Electrical staging provides maximum salt removal rates within the limiting parameters of good system design. Independently controlled current is applied to each electrical stage to remove a prescribed amount of the dissolved salts from the feedwater. Faraday's Law is the basis for calculating the amount of current needed in an ED system for transferring a specific quantity of salts. For ED calculations, Faraday's Law states that the passage of 96,500 amperes of electric current for 1 second will transfer one gram equivalent of salt.

Ohm's Law is used to determine the voltage requirements for a specific ED system. Ohm's Law states the potential or voltage of the electrical system is equal to the product of the current and the resistance of the system. The resistance is determined by the membrane stack components and the solution under treatment.

ED PROCESS TECHNOLOGY

During the electrodialysis demineralization process, feedwater containing dissolved ions is pumped at low pressure through the parallel spacer flowpaths across each membrane surface. When direct electric current is imposed on the membrane stack, the cations migrate towards the cathode and anions toward the anode. Ions are effectively trapped in alternating compartments which render the adjacent compartments partially deionized. This partially deionized or dilute stream is circulated through additional stages of demineralizing flowpaths until the desired product purity is obtained. The brine stream is recycled to the concentrating compartments to reduce the quantity of waste water. A small portion of the concentrate stream is diverted to waste as the brine blowdown to maintain solubility of the concentrated ions.

This process describes classical or unidirectional electrodialysis. The polarity of the applied direct current field remains the same throughout the demineralization process. Thus, the ions always move in the same direction and concentrate in the same brine compartments within the ED membrane stack.

Operational limitations on unidirectional membrane processes are imposed by the chemistry of the concentrate or brine stream. Long term, stable system performance is of critical importance for industrial operations and municipal supplies. Membrane fouling and mineral scale formation radically degrade system performance. Typical pretreatment for unidirectional membrane processes includes presoftening or treatment of the feedwater with acid and/or complexing agents such as polyphosphates. Such pretreatment and chemical feed requirements add the burdens of cost and waste treatment to the desalting process.

EDR PROCESS TECHNOLOGY

Electrodialysis reversal (EDR) is simply an ED process in which the polarity of the applied direct current potential is automatically reversed at regular 15 to 30 minute intervals. Polarity reversal changes the direction of ion movement within the membrane stack. As a consequence, former brine compartments become demineralizing compartments and the demineralizing compartments become brine compartments. Foulants and scale formed in the original concentrating compartments tend to be removed from the membrane surfaces and carried away. For 0.5 to 1.5 minutes after the current reverses, both the product and concentrate streams are purged as off-specification product water. The diluting compartments then return to making specified water quality. Special three way valving allows automatic switching of the feed, product, concentrate, and off-spec product streams.

The advantages of polarity reversal in the electrodialysis process are outstanding. EDR requires minimal pretreatment and is very forgiving of system upsets. Concentrate stream characteristics expand to allow Langelier indices of up to +2.2 and calcium sulfate saturation levels of 150 percent without the need for continuous chemical addition or special pretreatment. For applications in which water recovery is critical, Langelier indices up to +3.0 and $CaSO_4$ saturation levels up to 400 percent can be tolerated with the addition of very small amounts of acid and/or complexing agent to the concentrate stream. EDR is capable of concentrating salts and minerals to levels over 100,000 mg/l in the brine stream. Typical system recoveries are in the range of 80 to 90 percent.

A measure of organic fouling to membrane systems is the Silt Density Index or SDI. EDR is capable of stable operation on feedwaters with five minute SDI values exceeding 15. This level of SDI is typical of untreated surface waters and can occur in treated surface waters with less than optimal pretreatment. Further, EDR is now capable of sustaining long-term continuous exposure to 0.5 ppm residual chlorine. EDR membranes are capable of withstanding shock chlorination for microbial control with up to 50 ppm of free chlorine. Average membrane life is in the 5 to 10 year range. EDR units are capable of long-term operation at temperatures up to 45°C, pH range of 1 to 10, and a cleaning pH range of 0 to 11. This chemical stability enables use of a wide variety of cleaning agents for EDR systems in the occasional clean-in-place procedure. After a major pretreatment upset, EDR stacks may require manual disassembly for cleaning. If necessary, individual membranes can be scrubbed clean and reassembled into stacks with no loss in membrane life.

TRADITIONAL ROLE OF ED IN WATER TREATMENT

The traditional role of the ED process is for brackish water desalting for potable water production in regions where suitable drinking water sources are not available. The community of Dell City, Texas, faced the problem of an abundant but brackish well water supply. The high level of minerals rendered the water unsuitable for drinking purposes and difficult and costly in terms of household use and plumbing repairs. In 1967, an ED plant was commissioned which treated the 2,450 ppm TDS waters to about 600 ppm TDS. The ED plant at Dell City was subsequently expanded and updated to the new electrodialysis reversal technology. Water analyses and EDR plant performance characteristics are presented in Table 1.

Table 1

PERFORMANCE CHARACTERISTICS AND WATER QUALITY, DELL CITY, TEXAS

Plant Specifications	
Production:	378 M^3/day (100,000 USGPD)
Product Purity:	475 ppm TDS
Raw Water:	3,175 ppm TDS
Percent TDS Reduction:	85%
Desalting Stages:	4
Power Consumption:	2.8 kWh/M^3 Product (10.5 kWh/Kgal)

Water Quality (in ppm as the ion)

Ion	Feed	Product
Na	220	76
Ca	485	39
Mg	181	22
Cl	332	36
HCO_3	257	57
SO_4	1,700	245
TDS	3,175	475

CURRENT CHALLENGES TO THE WATER TREATMENT INDUSTRY

With increasing demand on water resources, new challenges must be addressed in water treatment efficiency, industrial contamination and control of specific, naturally occurring materials. Some of the challenges to be faced now and in the near future include saltwater intrusion of freshwater aquifers, nitrate contamination from agricultural runoff, the control of fluoride content in drinking water supplies, selenium poisoning of protected waters and natural wildlife areas, and contamination of raw water sources by organics and heavy metals.

Electrodialysis is a capable and versatile desalting technique for control of many ionic constituents contained in natural and contaminated waters. A number of cases are presented in which the specific removal capabilities of the electrodialysis process are discussed in terms of the new and existing challenges in water treatment. Design parameters, performance characteristics and feed and product water analyses for a number of electrodialysis plants are presented.

SALTWATER INTRUSION

Saltwater intrusion into our coastal freshwater aquifers is a problem borne of overuse. When the recharge rate of the groundwater aquifer is less than the rate of withdrawal, the danger of saltwater intrusion exists. Many rapidly growing coastal communities face the problem of well water quality degradation.

The major constituent of seawater is sodium chloride. Epidemiologic studies relate sodium in drinking water and blood pressure. Although there is inconclusive evidence, the sodium content of drinking water causes an elevation of blood pressure in the general population, there is concern for various high risk groups. The high risk segment of the population includes infants and pregnant women, victims of kidney disease or congestive heart disease, and those persons suffering from high blood pressure.

Electrodialysis has a long and proven history treating high sodium chloride waters. The Island Water Association of Sanibel Island, Florida, have operated electrodialysis and electrodialysis reversal desalting plants on a high NaCl content brackish water since 1973. The current production capability is 2.1 mgd. In addition, a large scale pilot study using EDR has been underway for a number of years. The performance characteristics for this plant and water quality parameters are presented in Table 2.

Table 2
PERFORMANCE CHARACTERISTICS AND WATER QUALITY,
SANIBEL ISLAND, FLORIDA

Plant Specifications

Production:	380 M^3/day (100,000 GPD)
Product Purity:	500 ppm
Raw Water:	2,930 ppm
Percent TDS Reduction:	86%
Desalting Stages:	4
Power Consumption:	2.0 kWh/M^3 Product (7.6 kWh/Kgal)

Water Quality (in ppm as the ion)

Ion	Feed	Product
Na	573	105
Ca	114	12
Mg	105	13
Cl	949	116
HCO_3	160	60
SO_4	394	65
F	1.9	0.9
pH	7.4	7.1
TDS	2,297	316

This example clearly illustrates the performance characteristics of electrodialysis reversal desalting of a high NaCl brackish water. This 4-stage plant is designed for 86 percent salt removal to produce drinking water quality of 500 ppm TDS or less. At the average feedwater salinity of about 2,500 ppm, the product purity is in the range of 350 ppm TDS. The EDR plant is capable of producing the specified product quality from feedwaters as high as 3,600 ppm in TDS. This aspect of flexibility is particularly important in desalting applications where the feedwater quality fluctuates on a seasonal basis. The EDR process is well suited for coastal area municipal water treatment.

NITRATE/NITRITE CONTAMINATION

One of the fastest growing drinking water problems worldwide is contamination of groundwater by nitrates. Two significant sources of nitrates in underground water sources are agricultural seepage of crop fertilizers and livestock wastes and from septic system discharge of human wastes. The ammonia and organic nitrogen components from these wastes are first converted to nitrite and then nitrate by surface dwelling bacteria. The nitrate and nitrite ions percolate from the surface into groundwater aquifers.

Nitrates and nitrites are toxic to humans. The human body is capable of reducing nitrate to nitrite in the saliva of all humans and in the gastrointestinal tract of infants during the first 3 months of life. Nitrate toxicity is evidenced by methemoglobinemia, which is a condition in which nitrate combines with hemoglobin and prevents normal oxygen-transfer functions. The result is the "blue baby" disease or asphyxia. The EPA has set a maximum contaminant level for nitrate in public water supplies at 10 mg/l as nitrogen or 45 ppm nitrate.

Electrodialysis is among several technologies used for nitrate removal from drinking water sources. The EDR process requires no chemical regeneration and is capable of delivering the desired level of demineralization with simple hydraulic staging. Operational data are presented in Table 3.

Table 3

NITRATE REDUCTION BY ELECTRODIALYSIS PERFORMANCE CHARACTERISTICS

Plant Specifications	
Production:	300 M^3/day (80,000 GPD)
Product Purity:	267 ppm TDS
	16 ppm NO_3
Raw Water:	1,068 ppm TDS
	92 ppm NO_3
Percent TDS Reduction:	75% TDS
	83% NO_3
Desalting Stages:	4
Power Consumption:	1.4 kWh/M^3 Product (5.2 kWh/Kgal)

Water Quality (in ppm as the ion)

Ion	Feed	Product
Na	46	12
Ca	166	36
Mg	47	11
K	20	11
Cl	75	12
HCO_3	512	144
SO_4	110	17
NO_3	92	16
pH	6.9	7.1
TDS	1,068	252

FLUORIDE CONTROL

Many water treatment plants fluoridate the municipal water supply. It is long established that a certain amount of fluoride in drinking water reduces the number of dental caries in the population. Too much fluoride in the water, however, can result in dental fluorosis, which is a discoloration or mottling of the teeth. The group most at risk of dental fluorosis are children under the age of fourteen.

Recently published national primary and secondary drinking water regulations from the EPA report a 4 mg/l maximum contaminant level (MCL) for fluoride in drinking water. The secondary MCL for fluoride is 2 mg/l. The optimum dosage for dental health is 0.7 mg/l.

Electrodialysis reversal is a reliable and well accepted process for removal of fluoride in regions with high naturally occurring concentrations of fluoride. Operational data and water quality parameters are presented below in Table 4.

Table 4
FLUORIDE CONTROL PERFORMANCE CHARACTERISTICS

Plant Specifications

Production:	946 M^3/day (250,000 USGPD)
Product Purity:	52 ppm TDS
	0.2 ppm F
Raw Water:	632 ppm TDS
	4.0 ppm F
Percent TDS Reduction:	92% TDS
	95% F
Desalting Stages:	4
Power Consumption:	1.0 kWh/M^3 Product (4 kWh/Kgal)

Water Quality (in ppm as the ion)

Ion	Feed	Product
Na	184	15
Ca	38	1
Mg	4	0.1
Cl	120	10
HCO_3	92	17
SO_4	192	7
NO_3	16	5
F	4.0	0.2
TDS	632	52
pH	8.9	7.6

SELENIUM POISONING

Selenium poisoning at the Kesterson National Wildlife Refuge in the San Joaquin Valley of California is a political and highly emotional issue. In this protected natural area, scientists have confirmed the toxic affects of selenium on birds, fish, and other wildlife. These toxic effects are evidenced by high rates of mortality, embryo deformities, and avian reproduction failures.

Selenium is commonly found in soil in concentrations of 0.03 to 0.8 ppm. Cretaceous shales, in particular, contain higher than normal concentrations of selenium. These sedimentary rocks are common in the western United States where alkaline soils render selenium more soluble in water. Irrigation drainage from agricultural tracts solubilizes and transfers selenium to downstream waterways.

Selenium is known to have specific toxic effects in humans at high dosage although it is an important nutritional element at low levels. The World Health Organization, as well as the National Interim Primary Drinking Water Regulations, recommend a maximum contaminant level of 0.01 mg/l for selenium. For the protection of freshwater aquatic life, the recommended maximum contaminant level for selenium is 0.035 mg/l in a 24 hour average. These recommended MCL's are an order-of-magnitude less than the typical concentrations of selenium in our poisoned waters.

Electrodialysis is capable of reducing the selenium content along with other soluble minerals when treating brackish waters. Operational data from past studies are presented in Table 5.

Table 5

SELENIUM REDUCTION PERFORMANCE CHARACTERISTICS

Plant Specifications	
Production:	114 M^3/day (30,000 USGPD)
Product Purity:	275 ppm TDS
	0.02 ppm Se
Raw Water:	1,960 ppm TDS
	0.11 ppm Se
Percent TDS Reduction:	86% TDS
	82% Se
Desalting Stages:	4
Power Consumption:	2.7 kWh/M^3 Product (10.5 kWh/Kgal)

Water Quality (in ppm as the ion)

Ion	Feed	Product
Na	337	61
Ca	191	16
Mg	44	6
K	20	2
Cl	432	61
HCO_3	573	106
SO_4	363	23
NO_3	1.9	0.4
Ba	0.15	0.1
Se	0.11	0.02
U	9.15	1.8

CONTAMINATION BY ORGANICS AND HEAVY METALS

In recent years, an alarming number of adverse health effects have been recognized worldwide as a result of contaminated water sources. Ground and surface water sources are subject to chemical pollution from improperly disposed industrial wastes. Many of these wastes contain dangerous and toxic heavy metal ions. Further, there is growing concern for the safety of our drinking waters from contamination by synthetic organic chemicals such as pesticides.

Decontamination of raw water sources is a difficult undertaking which frequently requires a broad spectrum of water treatment technologies. Some of these water treatment options include microbial digestion, incineration, precipitation and filtration, and membrane processes.

Electrodialysis is an effective membrane process for the reduction and removal of soluble ionic materials. Actual analytical results from a number of operating plants, pilot studies, and laboratory work are presented below. Table 6 illustrates the separation capability of EDR on a number of different heavy metals. These heavy metals and radionuclides are ionized in solution and thus are very effectively removed in the ED process. The typical rate of heavy metal removal approaches the design TDS removal of the ED plant.

Table 6
SEPARATION OF HEAVY METALS BY EDR
(analyses in ppm as the ion)

Ion	Feed	Product	% Removal Ion	% Removal TDS
Ag	250	25	90	95
	250	21	95	N/A
As	0.022	0.009	59	84
Ba	0.7	0.04	94	72
Cd	1.1	0.005	99	95
Cu	12.7	0.76	84	N/A
	12.6	0.32	98	N/A
Hg	12.0	0.11	97	N/A
Mo	21	0.23	98	N/A
Ni	2,630	360	86	N/A
Pb	4.2	0.11	98	N/A
	19.2	0.1	99.5	N/A
Ra	667	64	90	84
Th	54	10	81	84
U	9.15	1.8	80	84
	2.4	2.2	92	94

Contamination by naturally-occurring and man-made organics is also a recognized problem. Some synthetic organic contaminants are sparingly soluble nonpolar organic molecules, such as petroleum residues. Other organics found in water are relatively polar and long-chain humins, humic acids, and tannins. Since these macromolecules bear no permanent ionic charge, and are too large to be transferred through ion exchange membranes, removal of these constituents by the EDR process is not expected or observed.

However, there are a significant number of water soluble organic materials that do bear partial ionic character. If the molecular weight is low enough for these charge-bearing organics to pass through the ion permeable membranes, one could expect some level of removal in the EDR process. Laboratory study indicates that the low molecular weight organic acids are very effectively removed by electrodialysis.

These findings are further substantiated by total organic carbon analyses of various feed and product waters from a number of operating EDR plants in the United States. These analyses reveal a relatively low, but significant removal of TOC. Generally speaking, the percent TOC reduction is one quarter to one half of the design TDS removal in these operating plants. Table 7 presents the field data on the reduction of TOC levels by EDR.

Table 7

REDUCTION OF TOC LEVELS BY EDR

(analyses in mg/l)

Feed TOC	Product TOC	Waste TOC	% TOC Reduction	% TDS Reduction
6.6	5.0	-	24	50
4.9	3.1	-	37	67
5.3	1.7	2.0	68	92
2.6	1.7	3.5	35	90
1.9	1.7	-	10	86
2.4	1.7	-	29	86
2.9	2.0	4.5	31	59
4.7	3.3	-	30	87
3.8	3.3	-	13	N/A
4.1	3.7	-	8	66
3.2	1.8	6.2	44	88
4.8	2.8	15.1	42	78
3.1	1.8	4.1	42	88
4.8	1.7	2.7	64	94
2.0	1.7	-	15	86
3.6	3.6	-	0	84
4.1	2.4	9.1	41	82
4.8	2.8	15.1	31	59
3.4	2.3	21.5	32	83

CONCLUSION

Electrodialysis has a long and proven history for desalting brackish waters. As we face new challenges in water treatment, new roles develop for the existing technologies. Electrodialysis is an important and capable technique for reducing the concentrations of ionic constituents found in water. The traditional role of electrodialysis for brackish water desalting for potable use will certainly continue into the future. New applications for electrodialysis continue to develop.

Review of operational data for a number of electrodialysis plants illustrates the capabilities of this important technology in the strategies to meet some of our current challenges in water treatment.

Some of these challenges include: saltwater intrusion into freshwater aquifers, the contamination of nitrates and nitrites of well waters, fluoride control in municipal water, selenium poisoning, and contamination by organics and heavy metals.

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QUESTIONS AND ANSWERS

Linda Ruth Schmauss

AUDIENCE

I would like a brief summary of places that you think that EDR would fit in. Electrodialysis and reverse osmosis are sometimes battling nose to nose in some places. Where are some of the niches that you think that electrodialysis would really fit in and be a better solution to the problem than reverse osmosis?

LINDA SCHMAUSS

It takes careful evaluation of all these membrane treatment processes on any particular feedwater. Some of the places where electrodialysis has an advantage relative to reverse osmosis is in water recovery. The brine stream concentration is the one main factor in any membrane process. EDR plants, because of the reversal aspect, are capable of very high concentrations on the brine side. For example, calcium sulfate saturation levels in excess of 300 percent of saturation are typically achieved with some chemical injection into the brine stream of a EDR plant.

AUDIENCE

I want to clarify the definition of recovery. It is the ratio of product water produced to the amount of feedwater used. What is typical recovery for an EDR unit?

LINDA SCHMAUSS

Somewhere in the range of 85 to 90 percent. It is a very efficient process in terms of high recovery.

This paper was prepared by the editor based on a recording of the presentation. Where deemed appropriate, the presentation has been edited for clarity.

AUDIENCE

As I remember, the range of recoveries for reverse osmosis units in the state of Florida (someone can correct me) may be in the order of from 55 percent up to 85 percent.

AUDIENCE

Is there any advantage to staging or the utilization of separate stacks for brine concentration?

LINDA SCHMAUSS

Yes sir, there are. The question, I believe is, are there advantages to staging in the concentration of brines? Yes, staging in an electrodialysis plant provides a higher level of salt removal on the product side and an increased level of brine concentration on the brine side. With more stages, you can achieve greater levels of concentration as well as greater levels of demineralization.

AUDIENCE

How about on the power side?

LINDA SCHMAUSS

Well, certainly the higher the concentration of dissolved ions, the higher the levels of energy required to move those ions. There are two components of power in an electrodialysis plant. The first is the power required to pump the feedwater through the plant. The feedwater pump pressurizes the raw water up to about 100 psi and moves that through the stacks. The second component is the direct current that is required for salt removal. The current is related to Faraday's Law, to the amount of salt, or grams of salt, to be removed. So that the higher the concentration of salt removed, the higher the power requirement will be. A rough rule of thumb is about .25 kilowatt hours per 1,000 gallons produced per 100 parts per million of TDS expressed as calcium carbonate removed.

AUDIENCE

In the EDR process, referring to the reversal polarity, what happens to the organic foulants that are released from the membrane? Where do they go?

LINDA SCHMAUSS

They are typically carried out of the system. There is a blowdown from the recirculating brine stream and, this way, they are carried out of the system. EDR systems are very forgiving.

AUDIENCE

Out of the product side or the brine side?

LINDA SCHMAUSS

On both sides. At the time of reversal in the product line, a slug of water that is not meeting specification is present. That off-specification product water is purged from the system by an automatic conductivity actuated valve to waste and it is in this slug of off-specification product water that most of the seeds of scale formation and coagulants of organics are contained. They are discharged from the system.

AUDIENCE

Will EDR plants interfere with television or radio reception because of the rectifiers?

LINDA SCHMAUSS

In my short experience with Ionics I have never run into this. I do not believe that it would cause any problems. In some of our more automated plants that are computer controlled, cathode ray tubes are used in control centers that are located within 10 to 15 feet of the EDR plants. I would not anticipate any problem with TV reception.

AUDIENCE

Do you have any data yet on THM precursory removal by EDR?

LINDA SCHMAUSS

We have some data. It is more or less inconclusive at this point. Based on some literature that we have obtained, we found that the level of TOC removal in EDR plants can be, at times, related to the level of THM precursors. In one paper in particular, some note was made that the very low molecular weight organics that were present in this feedwater were the ones that were most readily converted to THM's in the final drinking water. As for interpreting these results, an EDR plant can only remove the low molecular weight organics, so we would anticipate the electrodialysis reversal process to be capable of reducing THM's and THM precursors but it has not yet been quantified. We are beginning a pilot study and we hope to obtain much more information on that. If we get that information we will, of course, publish it.

BASICS OF REVERSE OSMOSIS

by

Stuart McClellan
FilmTec, Inc.
West Palm Beach, Florida

DESALINATION IN SOUTH FLORIDA
August 21, 1987

BASICS OF REVERSE OSMOSIS

by

Stuart McClellan

Sales and Technical Representative

FilmTec, Incorporated

West Palm Beach, Florida

The phenomenon of osmosis has been known for many years but it has only been until recently that people have been able to utilize this phenomenon to produce potable or drinking water. In osmosis, where two solutions of varying concentrations are separated by a semi-permeable membrane, the solution of least concentration passes through the membrane to the solution of higher concentration. There are many examples of this in nature. One of them is in our own bodies where the body can absorb water through the stomach walls and other body cells by this phenomenon. This is also the reason why when people drink seawater they die of dehydration because the flow of fluid or water is reversed and water leaves the cells to enter the stomach.

In this process of osmosis, we have a term which is called osmotic head. This is the pressure which can be established by solutions of two different salinities on either side of a semi-permeable membrane. Theoretically, if pure water were put on one side and seawater on the other, there would be an actual movement of the water through the membrane which would continue until a column of fluid built up on the seawater side to a level which would be equivalent to approximately 350 psi. This would represent the potential of the osmotic difference (or pressure) between the two solutions.

By artificially imposing a pressure on the seawater column, we can reverse the phenomenon and actually squeeze freshwater from the seawater side to the side of less concentration. We call this reverse osmosis.

This paper was prepared by the editor based on a recording of the presentation. Where deemed appropriate, the presentation has been edited for clarity.

If we have those same solutions separated by a membrane and arrive at a steady state where there is either no flow or the flow is balanced in both directions, we have an osmotic equilibrium. In a seawater system the osmotic head would be the equivalent of about 350 psi. This is why, in seawater reverse osmosis systems, we have to operate at very high pressures. First, we have to overcome the natural osmotic pressure of the fluid before we can begin to reverse the phenomenon of osmosis.

Some osmotic pressures for various solutions are:

Solution	Osmotic Pressure
35,000 ppm Sodium Chloride	400 psi
1,000 ppm Sodium Chloride	11 psi
2,000 - 3,000 ppm TDS (Typical Florida Brackish Water)	30 - 40 psi

Reverse osmosis is a membrane separation process and in addition to desalting the fluid stream, it also acts as a super-filter by removing all of the suspended materials in the water. Examples of other types of filtration processes are micro-filtration which is primarily the cartridge type filters or swimming pool type filters; ultra-filtration which is a membrane process, and nano-filtration which is in between true reverse osmosis and ultra-filtration.

Nano-filtration is a membrane process just recently reintroduced. There are other new membranes on the market that also work in this area. Nano-filtration membranes can be used for membrane softening on existing municipal water supplies where a lot of salt rejection is not needed but where there are a lot of organic particulate matter that must be removed. Nano-filtration operates at much lower pressures than conventional brackish water RO membranes. Recent studies show that membrane softening, or nano-filtration, has good promise for the reduction of precursors which cause Trihalomethanes (THM's). THM's are the objectionable chemical byproduct which result from high level chlorination of certain water sources used for drinking supplies.

Previous speakers have already talked about the term recovery, but in the RO industry we also have another consideration and that is salt rejection. As mentioned previously, not necessarily all of the dissolved salts are 100% rejected. We express the salt rejection characteristic, or performance of a membrane, as a percentage of the quantity of salt in the product versus the feedwater. Commonly, seawater RO membranes will reject 99+ percent; brackish water RO membranes will reject on the order of 95 percent to 97 percent; and nano-filtration membranes reject on the order of 70 to 85 percent of the dissolved salts in the water.

A general rule for membrane systems, the higher the salt rejection, the lower the flux. Or another way to look at it, the higher the salt rejection, the higher the pressure that you need to produce freshwater out of the membrane system.

There are a lot of parameters that have to be acknowledged and studied when people are designing RO systems. These include:

- Feedwater Pretreatment
- System Pressure
- Feedwater Conductivity (Salinity)
- pH
- Flow rate
- Temperature
- Product Water Recovery

The general effect of pressure on the production of water is that as you decrease the water flow through the membrane it will improve the salt rejection characteristics of that membrane.

The effect of temperature on membranes is that as the temperature increases, the permeate will increase. However, you are going to have a reversal effect in that the salt rejection decreases slightly.

pH is also another parameter which can affect the performance of an RO membrane and as the pH increases, you have a slight increase of the water flow through the membrane but you can have strange or unusual happenings with regard to salt rejection. At the near neutral pH range, you get your best salt rejections and as you go to other extremes, you lose some of the salt rejection capabilities of the membrane.

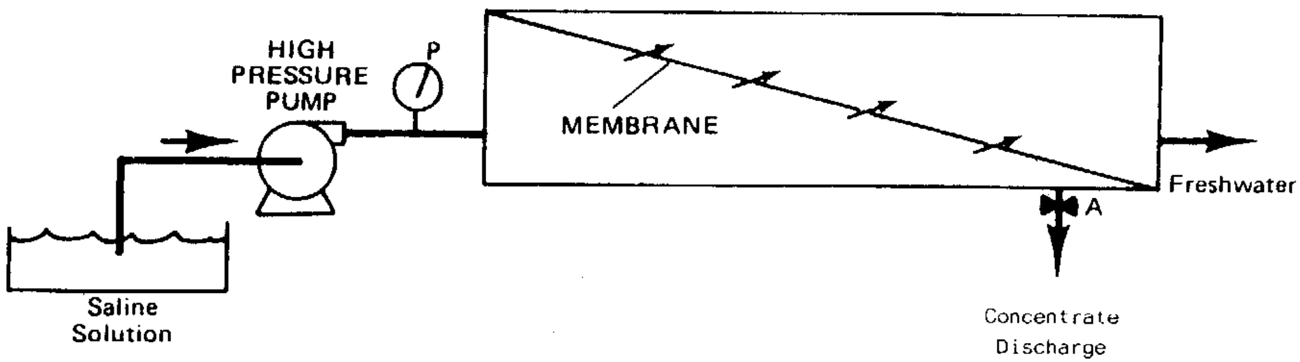
With regard to the salinity of the feedwater, the higher the concentration is, the less percent rejection for a particular type of membrane. So if you operate a brackish water membrane on a feedwater which contains 1,000 ppm of TDS, the salt rejection will be, percentage-wise, better for that same particular membrane than if it is operated on a feedwater with say 10,000 ppm of TDS, provided that all the other operating parameters are the same.

Figure 1 is a simplified diagram that illustrates the basic elements in any RO system. The pressure pump overcomes the osmotic head and actually provides a driving force to push the water through the membrane. The regulating valve on the concentrate (brine) discharge keeps the back-pressure on the brine side of the membrane.

In an RO system we do not obtain all of the feedwater as product. This characteristic is called recovery and is expressed as a percentage of the feed which is converted to product. Conventionally speaking, RO systems operate between 50 to 75 percent recovery. As recovery increases, the salts remaining in the membrane assembly are concentrated to a higher level and this has an adverse affect on both the salt rejection and water production.

There are limitations on recovery. It would be ideal to have the recovery as high as possible and lose only a small amount as concentrate or reject water that would carry away the dissolved salts and suspended solids that are rejected by the membrane. One problem with this is the osmotic pressure. If the recovery is too high, the remaining water is very concentrated and the osmotic pressure increases. This means that the pumping capabilities must also be increased to overcome the osmotic head so as to produce a practical flow.

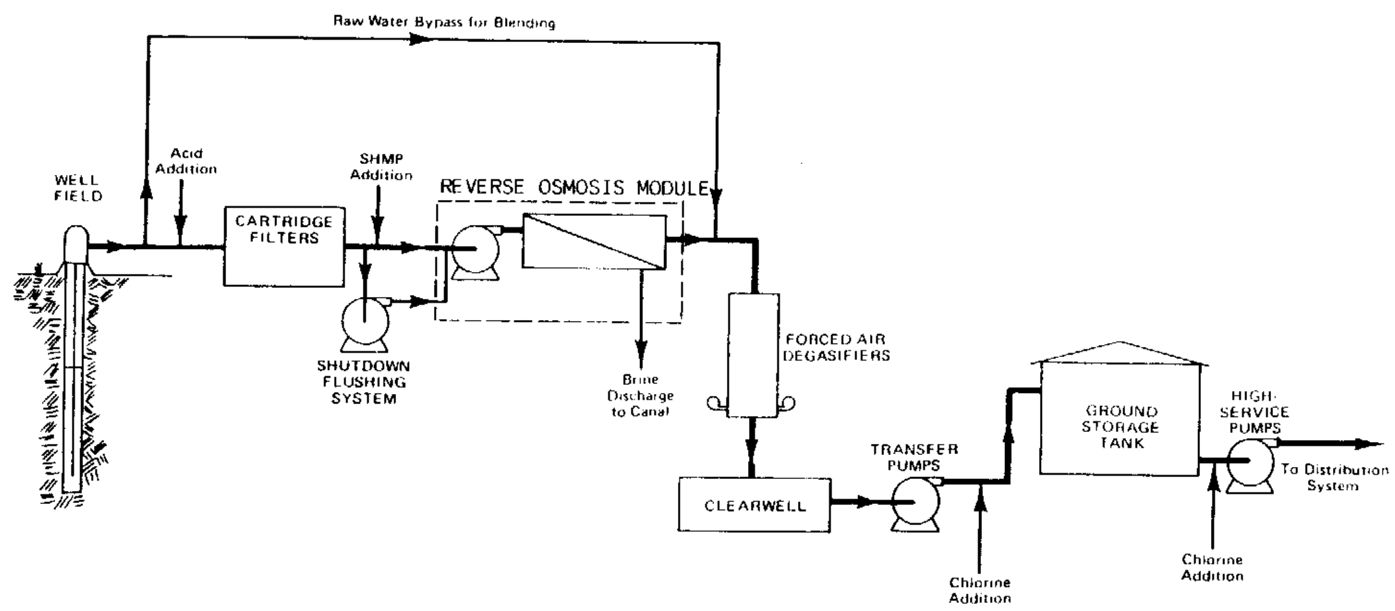
The other major concern with recovery is that, as we concentrate the dissolved salts in the water, they tend to precipitate out and scale the surface of the membrane and can actually plug the membrane assembly or permeator. If the recovery is 50 percent, essentially the



A membrane assembly is generally symbolized as a rectangular box with a diagonal line across it representing the membrane.

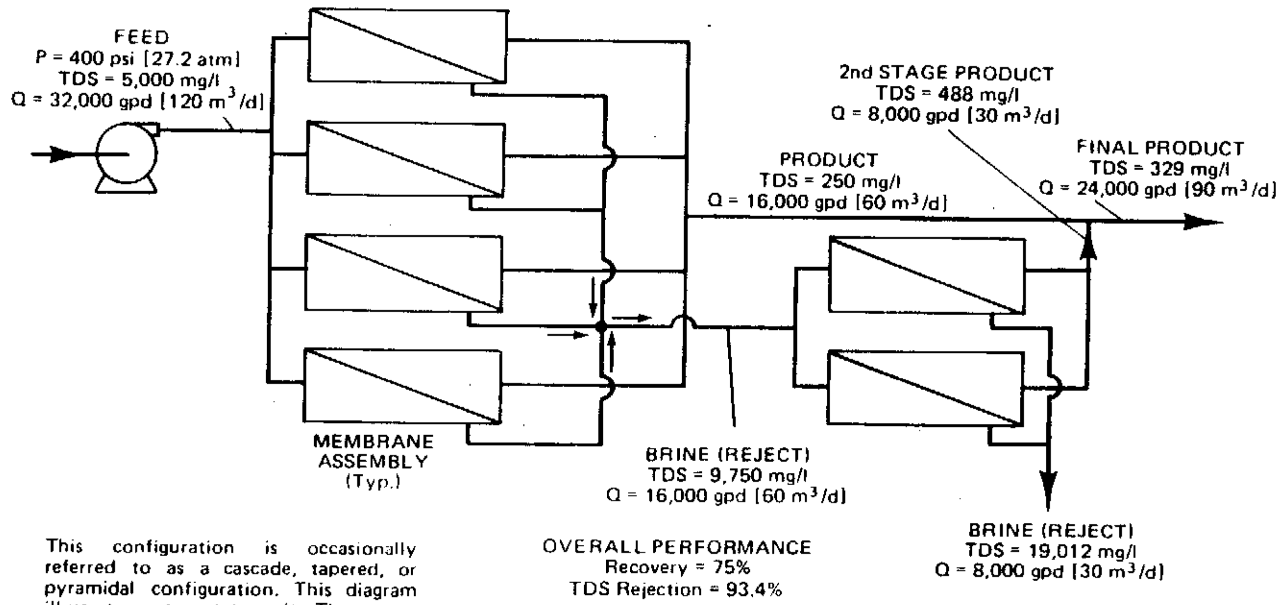
This figure is adapted from *The U.S.A.I.D. Desalination Manual* (Buros, et. al. 1980) and is used courtesy of the U.S. Agency for International Development.

FIGURE 1 Basic Elements of an RO System



This figure is adapted from *The U.S.A.I.D. Desalination Manual* (Buros, et. al. 1980) and is used courtesy of the U.S. Agency for International Development.

FIGURE 3 A Typical Florida RO Facility



This configuration is occasionally referred to as a cascade, tapered, or pyramidal configuration. This diagram illustrates a two-state unit. Three-stage units (with recoveries of 85 to 90%)are also used.

This figure is adapted from *The U.S.A.I.D. Desalination Manual* (Buros, et. al. 1980) and is used courtesy of the U.S. Agency for International Development.

FIGURE 2 A Simplified Diagram of a Multi-Stage RO Unit concentration of ions would be double on the brine side, whereas if you go to 75 percent, the concentration of the salts is four times. So recovery quite often is limited by the chemistry of the water being treated. It also has to do with the hydraulic nature and configuration of the RO system. Manufacturers of membranes have certain flow restrictions with limits set on the upper and lower rates of flow through a membrane system. Therefore, there are times when recovery will be affected by the number of permeators in the system or the arrangement of these permeators.

In addition to the other factors of pressure, concentration, and temperature, most membranes exhibit a declining flux rate with time. This is very dependent on the particular membrane being studied but it is suffices to know that time does have, or can have, an effect on the performance of a membrane. In addition to time, there are actually other factors in connection with the operation of the membrane such as fouling and cleaning which have an effect on the performance over a long time period.

Basically, commercial membrane devices have been produced in spiral wound, hollow-fine fiber, tubular, and plate-and-frame configurations. The spiral wound and hollow-fine fiber are the most commonly used membrane configurations for municipal water treatment. Special applications and industrial processes use tubular and/or plate-and-frame style membranes even today.

One thing that has not been touched on before is that all RO systems, irrespective of size or style of membrane, have a cartridge pre-filter which is primarily provided to keep large suspended materials from mechanically clogging the membrane device. Pressure gauges are used to determine when to replace the cartridges in the pre-filter. In addition, most large RO systems will have a pressure switch on the suction of the RO pump so that if the cartridge filter becomes clogged, or if you lose the supply water, it will protect the RO pump by shutting it down based on the lack of sufficient suction pressure.

Most RO pumps are not sized precisely, or cannot be purchased precisely to meet the individual demands of an RO system. So, usually there is a pump discharge adjustment valve to regulate the pressure required to produce the design flow through the membrane system. This complements the valve that is used to regulate the concentrate flow which affects the recovery.

Figure 2 is a simplified diagram of a multi-stage RO system showing more than one membrane assembly in parallel. This is illustrative of what an actual small brackish RO plant would look like. The concentrate flow through the system is controlled by a valve in the concentrate stream. There also may be individual controls on the concentrate stream of each permeator to more accurately balance the flow through each membrane assembly.

In order to maximize the possible recovery for a particular plant and still meet the hydraulic requirements of the membrane device, system manufacturers will stage the permeators. In this case, there is a two stage system showing a 4 x 2 array, which is a very common array for spiral wound and hollow-fiber systems. In each stage, the hydraulic flow of water across the surface of the membrane is equivalent to 50 percent recovery. Yet, the net effect of the entire system is that the recovery is 75 percent.

In addition to the cartridge pre-filter, most membrane systems add chemicals to the feedwater. The most common chemical being acid for control of calcium carbonate scale, as well as in some cases, to control the pH environment for certain membranes. In addition to that, there are plants which will use an anti-scalant or sequesterant in the feedwater. Years ago the standard was to use sodium hexametaphosphate (SHMP). These days there are a lot of synthetic anti-scalants on the market which do the pretreatment much more efficiently and effectively.

Figure 3 illustrates a typical municipal RO facility in Florida. In addition to the pretreatment and the RO devices, there is also a degassification unit to remove objectionable gasses that may be in the product water. RO membranes used in water treatment do not reject dissolved gasses such as oxygen and carbon dioxide. In particular, Florida wells quite often contain hydrogen sulfide which is a gas that has a rotten egg smell. This can be removed by degassification after the water passes through the membrane. Then in a municipal system, the product water may be treated to re-adjust the pH to stabilize it, as well as the addition of chlorine for disinfection so as to maintain safe potable water in the distribution system.

In summary, I would like to say that reverse osmosis is a process that has been around for a long time and it is by far the largest membrane process employed throughout the State of Florida to produce drinking water. It can be a very efficient and reliable process and, by maximizing recovery while preventing fouling and scaling, a properly designed facility can provide a cost-effective means of desalting brackish water for potable use.

RO MEMBRANES

by

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DESALINATION IN SOUTH FLORIDA
August 21, 1987

RO MEMBRANES

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INTRODUCTION

The selection of a polymeric material which will produce durable and cost-effective reverse osmosis membranes is a formidable task.

For nearly a decade (in the 1960's), while researchers tried to improve on the asymmetrical membranes made by Sourirajan and Loeb, the only product choice was the cellulose acetate membrane. It was not until 1970 that a second membrane material became available.

Permasep Products, a division of the Du Pont Company, commercialized their B-9 polyamide membrane for the desalination of brackish water. It took another five years, however, to widen the choice. By 1975 several new membranes were available. In addition to different variants of cellulose acetate and the B-9 polyamide, Teijin of Japan introduced PBIL (polybenzimidazolone) membranes and UOP's Fluid Systems Division commercialized their PA-300/RC-100 thin film composite membranes. Du Pont added their B-10 fully aromatic polyamides for seawater desalination. The following five years saw a proliferation of thin film composite membranes, with Hydranautics version of the PA-300/RC-100, FilmTec with its FT-30 polyamide and Toray with its PEC-1000 polyether membrane. Cellulose triacetate also made its debut as RO membrane material in the form of Toyobo's "Hollosep" hollow fine fibers for seawater applications and Dow's "Dowex" permeators for brackish applications. The range of useful materials continued to expand. Significant additions to the palette of commercial membranes over the past several years were Du Pont's B-15 aramid membrane in spiral wound configuration, B-10T membranes for seawater desalination at high feed pressures up to 1200 psig, FilmTec's high rejection version of the FT-30 and a line of "nano-filtration" membranes designated NF-40, NF-50, and NF-70, whose performance is between RO and UF membranes.

This paper gives an overview of currently available RO membranes, discusses some of their chemical and physical properties and reports on some of their applications.

MEMBRANE SEPARATION PROCESSES

Reverse osmosis is only one of several separation processes using membranes. Shown in Table 1 are membrane separations, processes.

Table 1

MEMBRANE SEPARATIONS

Driving Force	Process	Application
ΔC	Dialysis	Artificial Kidney Purification of polymer solution
ΔE	Electrodialysis	Potable Water Concentration of galvanic rinses
ΔP	UF	Purification of polymer solution
ΔP	RO	Desalination Concentration of valuable low MW components Gas separation
ΔP	Piezodialysis	Separation of electrolytes

These separation processes can be categorized based on the driving force used to achieve the separation.

Applications of membrane processes are found in a wide variety of fields. RO membranes have found use particularly in desalination, the removal of dissolved salts from feedwaters varying in concentration from a few ppm to full strength seawater up to 50,000 ppm.

These membranes are also used in industrial (electronics, chemical industry, and pharmaceutical), medical, food, waste, and mining applications.

Depending on the application, the membrane structure will vary. RO membranes are all asymmetrical with a dense skin on the top side and a porous support underneath as shown in Figure 1.

1 - Ultrathin Skin
2 - Intermediate Porous Transport Layer
3 - Porous Support
4 - Reinforcing Fabric - Woven or Non-Woven

FIGURE 1
Cross-Cut of an RO Membrane

Such a structure can be obtained from a homogeneous polymer or also prepared from different polymers such as the composite membrane. The density of the membrane skin determines the appropriate process and separation (see Figure 2).

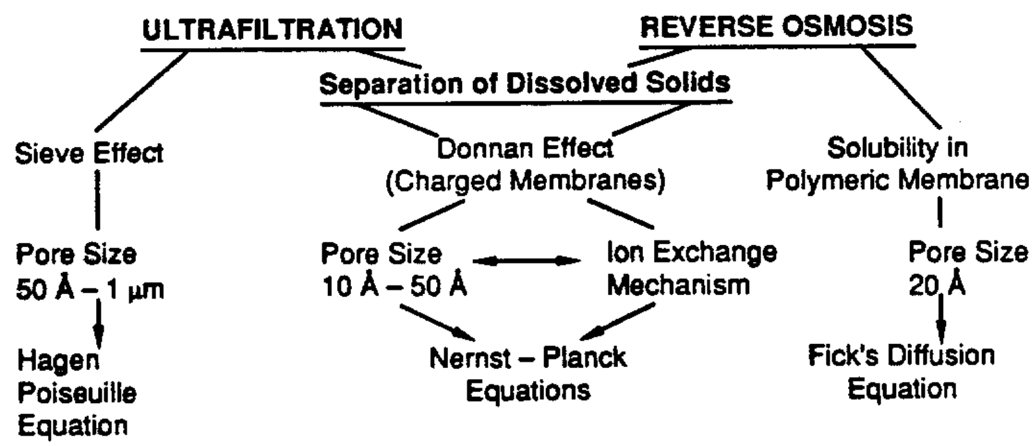


FIGURE 2
Schematic Showing Transport Mechanism for Membrane Processes

CHEMICAL CLASSIFICATION OF RO MEMBRANES

A classification of commercial RO membranes by chemical structure is useful since it permits the prediction of membrane properties in an aqueous environment. Although membrane manufacturers never disclose the exact structure of their products, it is possible to categorize them based on examples given in the patent literature.

By far the most desirable reverse osmosis membranes are derived from aromatic monomers and fall into the class of fully aromatic polyamides. Table 2 shows the more common polymeric membranes in decreasing order of commercial importance.

Table 2
CHEMICAL CLASSIFICATION OF RO MEMBRANES

- Aromatic Polyamides
  - a. Fully aromatic
  - b. Aryl-alkyl polyamides
  - c. Polyurea
- Cellulose Acetate
- Cellulose Triacetate
- Polybenzimidazolones
- Polypiperazineamides
- Sulfonated Polycyclicethers
- Sulfonated Polysulfones

FULLY AROMATIC POLYAMIDES

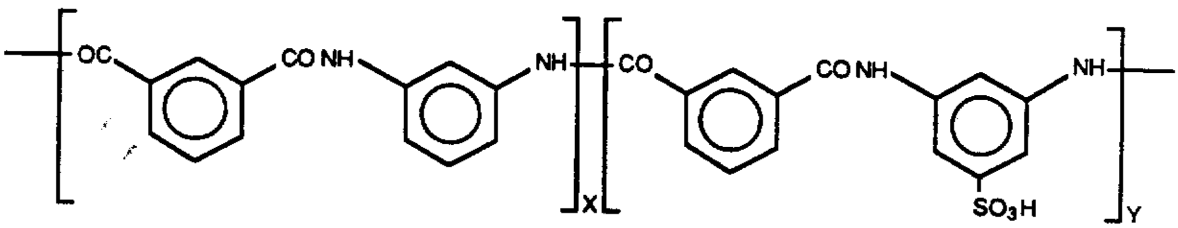
The class of polyamide membranes is characterized by many desirable properties such as long operating life as well as good resistance towards the many chemicals encountered in the feed streams to be desalted, including polyelectrolyte coagulants, surfactants, biocides, antiscalants, and pH conditioners (see Table 3).

Table 3

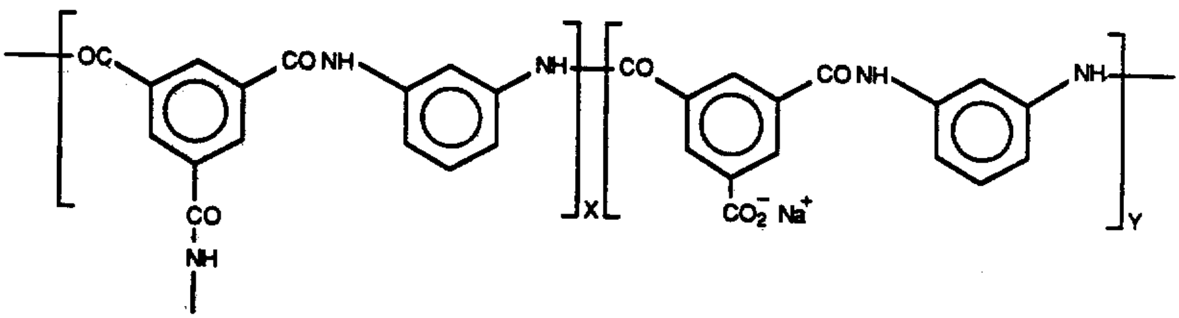
FULLY AROMATIC POLYAMIDES

Hollow Fine Fibers	PERMASEP® B-9	Du Pont
Hollow Fine Fibers	PERMASEP® B-10	Du Pont
Flat Film (Spiral)	TW/BW/SW/HR-30	FilmTec
Flat Film (Plate and Frame)	HR-95, HR-99	DDS
Flat Film (Tubular)	ZF-99	PCI
Flat Film (Spiral)	PERMASEP® B-15	Du Pont

As reflected in Table 3, there are many commercial membranes based on this chemistry. Two types of polymers can be differentiated, one consisting of linear molecular chains with the general formula:



and the other group, which consists of cross-linked polyamides containing carboxylate groups instead of sulfonate groups with the general formula:



Most of Du Pont's membranes fall into the linear polyamide group such as B-10T, B-9, and B-15 and therefore, can be dissolved in polar solvents and spun into hollow fine fibers or cast into flat film asymmetric membranes. Another advantage is that the membrane, in spite of its asymmetric structure, is made of one material, thus eliminating adhesion and compatibility problems between thin skin and supporting structure.

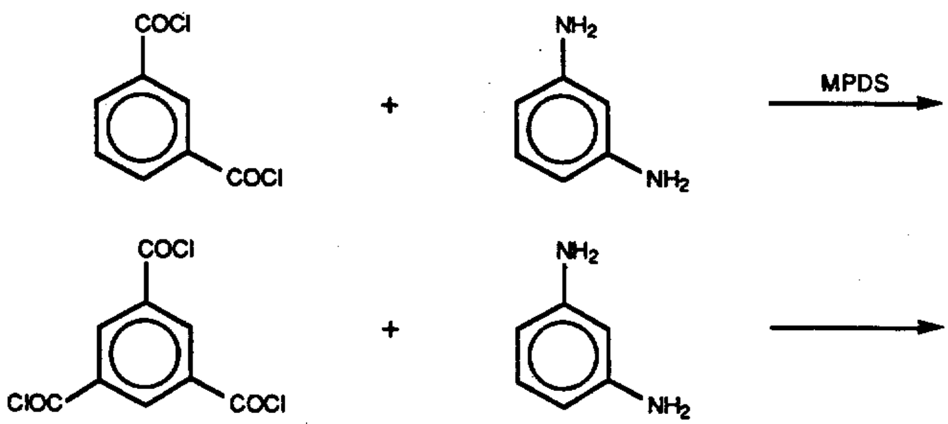
To manufacture cross-linked membranes, such as FilmTec's FT-30, different steps must be taken. The fully aromatic polyamide skin is formed by interfacial polymerization on a porous substrate. Since the polyamide is cross-linked, it is insoluble, providing some advantage in special applications. At low pH operation, greater durability is exhibited by the cross-linked polyamide. In other properties, such as the resistance to oxidants, reducing agents and alkaline cleaning agents with abrading components, the cross-linked types are at a disadvantage.

The polyamides offered commercially by DDS (De Dansk Sukkerfabriker) and PCI (Paterson Candy International) are variations of FilmTec's FT-30 membrane.

Little is known about the polyamide membranes offered by DSI (Desalination Systems, Inc. Desal Plus) and the one developed by Culligan for home RO applications.

ARYL ALKYL POLYAMIDES/POLYUREA

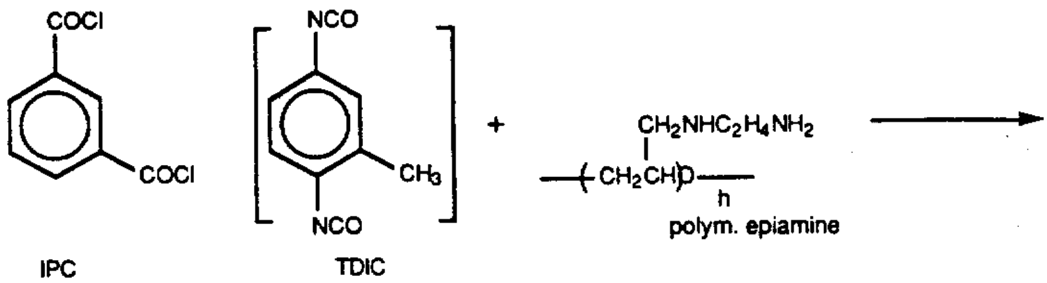
While fully aromatic polyamides are derived from intermediates such as isophthaloyl chloride and phenylene diamine (1) or trimesoylchloride and m-phenylene diamine (2),



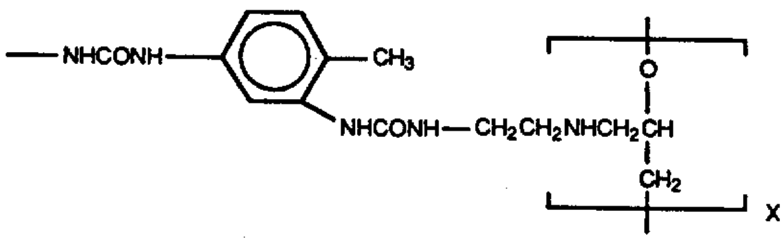
(1)

(2)

aryl alkyl polyamides and polyurea are derived from the following intermediates:



The Fluid Systems Division of UOP was the first company to commercialize a thin film composite polyamide membrane under the designation of PA-300. Membrane life of PA-300 was found to be inferior to a polyurea analog, possibly due to the sensitivity of the alkyl portion of the aryl/alkyl polyamide to oxidants. The polyurea, later introduced as RC-100, likely has the following structure:



Even this improved polymer, however, required protective coatings (PVA) for proper handling during cartridge manufacturing.

Other companies such as Hydranautics, Toray, and Nitto Denko are believed to have employed similar chemistry in making their composite membranes.

One common feature of these polymers is their slightly cationic character due to the excess of amino groups. This makes the membranes sensitive to anionic polyelectrolytes (coagulants), which contrasts the fully aromatic polyamides which carry a weakly anionic charge and therefore, show no interaction with the anionic polyelectrolytes. However, on occasion, sensitivity is exhibited towards cationic polyelectrolytes, usually through considerable loss of flux.

CELLULOSE ACETATE

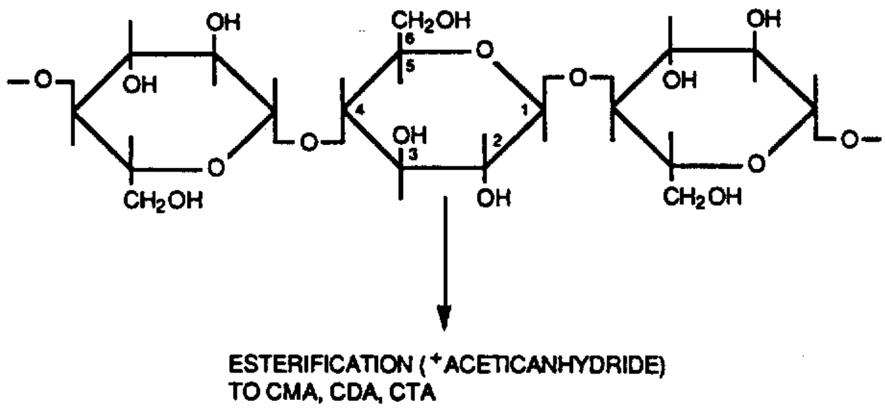
A large number of manufacturers offer cellulose-derived RO membranes. Historically, cellulose was the first material used successfully in the preparation of commercial RO membranes and has several valuable properties, which have prevented its replacement.

While there are a considerable number of variations, most manufacturers start out with cellulose triacetate and subject this material to a secondary hydrolysis.

Since the cellulose triacetate has low water flux, this secondary hydrolysis leads to improved flow suitable for flat-film derived devices such as spiral wound cartridges and plate and frame arrangements:

SYNTHETIC MEMBRANES

THE CHEMISTRY OF CELLULOSE –



The chemical variations possible with this basic structure are numerous and have been researched extensively. Currently the chlorine resistance of this membrane is the desired property. However, pH sensitivity and tendency for microbiological degradation are still problems with the membrane.

The importance of the membrane's composition is reflected by Figure 3 which illustrates how flow and salt rejection are interrelated and can be controlled. The graph also indicates the inherent weakness of the cellulose acetate membrane. In time, estergroups will hydrolize and salt rejection will gradually be lost as flow increases. With increasing hydrolysis, biological attack also will become easier and the membrane's function and integrity will be lost.

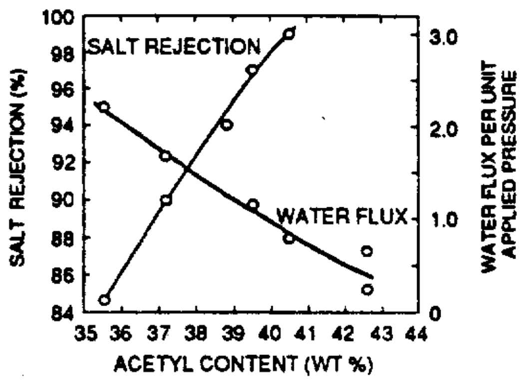


FIGURE 3

Flow and Salt Rejection of CA Modules [10]

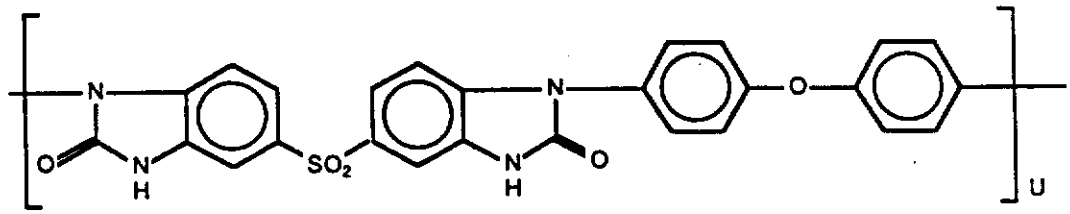
CELLULOSE TRIACETATE

Due to its relatively low flux, the cellulose triacetate membrane is used primarily in hollow fine fiber form. This configuration offers more surface area of membrane per unit volume of pressure vessel. Toyobo offers HFF CTA membranes for seawater desalination and

Dow provides HFF CTA permeators for brackish water in regular and low pressure versions. While CTA membranes have somewhat greater pH stability and resistance to microbiological attack, these properties are still reason for concern.

POLYBENYIMIDAZOLONE MEMBRANES

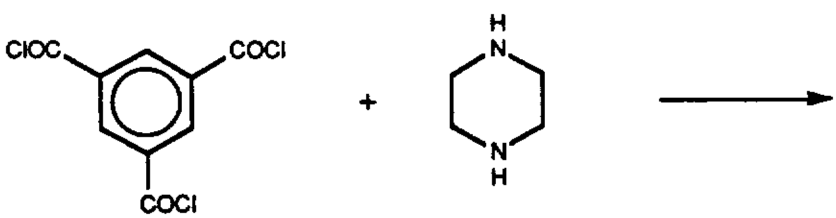
Teijin of Japan has developed this membrane. The structure is generally presented as follows:



Chemically, the material excels in its durability and lack of reactivity. However, due to its relatively low flux and additional sensitivity to compaction under pressure, there has been no commercial success with this material.

PIPERAZINEAMIDES

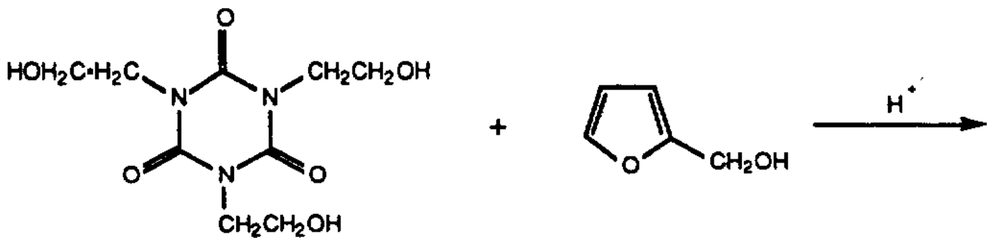
This membrane material is made by reacting mesylchloride with piperazine and has been used by several manufacturers:



Limited work was done by North Star Research Institute (NS-3090). Later, Nitto Denko and Toray employed similar chemistry. Today FilmTec's nano-filtration membranes belong to this family and efforts elsewhere have been reported. The interesting property of this polymer is a selective high rejection of bivalent anions such as SO_4 and low rejection of chlorides. This characteristic removes hardness from water and makes economics sense since feed pressures can be lower than in the RO process, where all ions are rejected.

SULFONATED POLYCYCLIC ETHERS

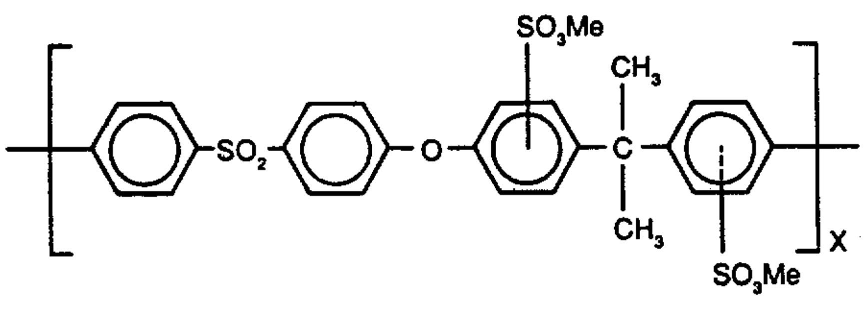
This membrane material was again pioneered by the North Star Research Institute and resulted in the NS-300 membrane. Toray uses similar chemistry in its composite PEC-1000 membrane.



This membrane material offers the most impressive initial RO performance of commercial products; however, a high sensitivity towards chlorine and even dissolved oxygen in the feedwater has kept this membrane from gaining commercial acceptance.

SULFONATED POLYSULFONE

Membranes made of sulfonated polysulfones have a chemical structure as follows:



They provide the elusive property of chlorine resistance. However, to date it has been difficult to provide the high flux and salt rejection needed for a cost-effective RO membrane material. Nevertheless, Millipore and DSI have utilized this chemistry for some of their commercial products.

OUTLOOK

The major competitors in the RO membrane field are pursuing leads in different areas. In the seawater area, Du Pont has pioneered the high-pressure membranes such as the B-10T, which permits operating pressures as high as 1200 psig. This capability leads to higher conversions and smaller pretreatment facilities--an economic feature especially attractive for large plants. Membrane devices for even higher operating pressures are on the drawing board.

In brackish water desalination, high conversion rates have traditionally been achieved, but current membrane offerings are striving to provide increasingly lower energy consumption by achieving comparable operating results at lower feed pressures.

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CASE STUDY: SANIBEL ISLAND ELECTRODIALYSIS PLANT

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DESALINATION IN SOUTH FLORIDA
August 21, 1987

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INTRODUCTION

The Island Water Association, Inc. (IWA), is a member-owned, non-profit corporation chartered under the laws of the State of Florida and franchised by Lee County to be the exclusive supplier of water to Sanibel and Captiva Islands. Prior to the inception of IWA, water for potable use was provided by the individual property owners who used wells, cisterns, and bottled water. The construction of a causeway connecting the islands to the mainland in 1963 led to a population growth which required a central supply.

The IWA commenced operations in 1966 by constructing a distribution system, three pumping stations, and a 9,500 foot underwater transmission line connecting Sanibel to Pine Island.

Purchased water from Pine Island was the IWA's sole source of supply until November 1973, when a 1.2 mgd electrodialysis (ED) plant, built by Ionics, Inc., was commissioned. In 1975, this plant was expanded to a capacity of 2.1 million gallons per day (mgd).

By 1978, the total dissolved solids (TDS) of the well field supplying the ED plant had increased so far as to reduce the plants capacity and significantly increase its operating costs. This well field was being supplied with water from the Hawthorn aquifer. Only by abandoning the higher TDS wells and increasing the pumpage rate of the lower TDS wells was the IWA able to seek a new source of raw water. Another aquifer, the Suwannee, was located containing a large volume of high TDS water, over 3,000 TDS. Subsequently, a new reverse osmosis (RO) facility, built by Hydranautics, Inc., was commissioned to treat this water. The RO process had the advantage of being able to economically treat this higher TDS water.

In 1980, the first RO train was installed to meet increased system demand. At that time, the general consensus of opinion was to add additional RO trains to satisfy future needs and gradually phase out the ED plant. An indepth cost benefit study was prepared to determine if and when this should be accomplished.

There were many suggestions from the plant manufacturers and the IWA staff. The ED plant was being used as a peaking facility with its maximum demand being 1.6 mgd. The estimated cost to upgrade one ED bank was $46,729 or $654,206 for all 14 banks. Fourteen upgraded banks would produce 2.1 mgd. An RO train, with all its appurtenances, cost $710,120, and could produce .605 mgd. Three RO trains, at a total cost of $2,130,360, would be required to replace the capacity of the ED plant. These costs are compared in Table 1. It was apparent that upgrading the ED plant involved the least capital cost. Slightly lower RO production costs would take over 10 years to become cost effective.

However, the most critical consideration concerned the feedwater. A reliable, consistent supply of feedwater was essential before IWA could even consider the plant technology. ED production costs rise sharply as feedwater TDS increases. The upper limit of economically treatable water was determined to be 3,000 TDS. The Suwannee aquifer, which was supplying the RO plant, was ruled out because its high TDS water would significantly increase the ED operating costs. There were discussions of seeking other distant well fields; however, these, too, were quickly eliminated because of the high capital cost of new pipelines and pumping equipment. IWA even researched the possibility of relocating the plant to an area where there was an adequate supply of suitable feedwater. Unfortunately this, too, was not cost effective.

The only practical solution would be to use the existing well field, but that was rapidly deteriorating. An evaluation was done, and it was deemed that with a combination of well rehabilitation and proper operation and maintenance procedures, the existing well field could be used for many years.

Table 1

COMPARISON OF CAPITAL COSTS TO UPGI

VERSUS COST TO EXPAND THE I

(in 1982 dollars)

RO Plant Expansion Cost to Add One Train:

Degasifier (1/3 cost)

Pipeline (1/3 cost)

Monitor Well (1/3 cost)

Well

Train

One RO train will produce 605,000 gallo
therefore, the capital cost per day per

$$\frac{\$710,120}{\$605,000} = 1{,}173.75 \text{ per K gal/day}$$

ED Plant Upgrade Cost to Refurnish One Bank:

Stack Components

Air Conditioning (1/14 cost)

Repair Building Room (1/14 cost)

Replace Trench Grates (1/14 cost)

Major Electrical Preventative Maintenance (1/1

Refurbish Stack Hardware/Electrical Wiring (

New Electric Drive for Overhead Crane (1/14

Well Field Refurbishment (1/14 cost)

One ED bank will produce 105,000 gallon
the capital cost per day per 1,000 gall

$$\frac{\$\ 46,729}{\$105,000} = \$445.04 \text{ per K gal/day}$$

Subsequently, both the well field and plant were rehabilitated. It is now five years later and both have been operating as anticipated.

WELLS

The raw water supply is a key factor in the successful operation of a desalination water treatment plant. The water must be of a usable quality, economically and within design limits, and delivered in the needed quantity at a required pressure. Some wells supplying the ED and RO plants have experienced quality declines and/or discharge problems.

Problems in the raw water source can result from well construction, aquifer (water quality) decline, well efficiency deterioration, and equipment failure. These problems are best identified by an effective monitoring program. The relative inexpense of measuring water levels and water quality parameters versus the loss of expensive equipment, wells, and more expensive treatment costs is a cheap form of insurance.

The IWA has consistently upgraded its monitoring program over the years. Water levels and water quality have regularly been measured in the production wells supplying both the ED and RO plants. This data was used to identify dramatic water quality fluctuations in the Hawthorn wells and rapid declines in Suwannee well specific capacities.

HAWTHORN WELLS

Monitoring identified sudden water quality declines in some Hawthorn production wells. Figure 1 shows a plot of total dissolved chlorides versus time for Well H9. Water quality declines were also noted in other Hawthorn production wells. The monitoring then in place was only for intermittent water quality measurements. No pumping levels or withdrawal amounts were measured. The IWA then determined to initiate an investigation of the Hawthorn wells and upgrade the monitoring program for all wells.

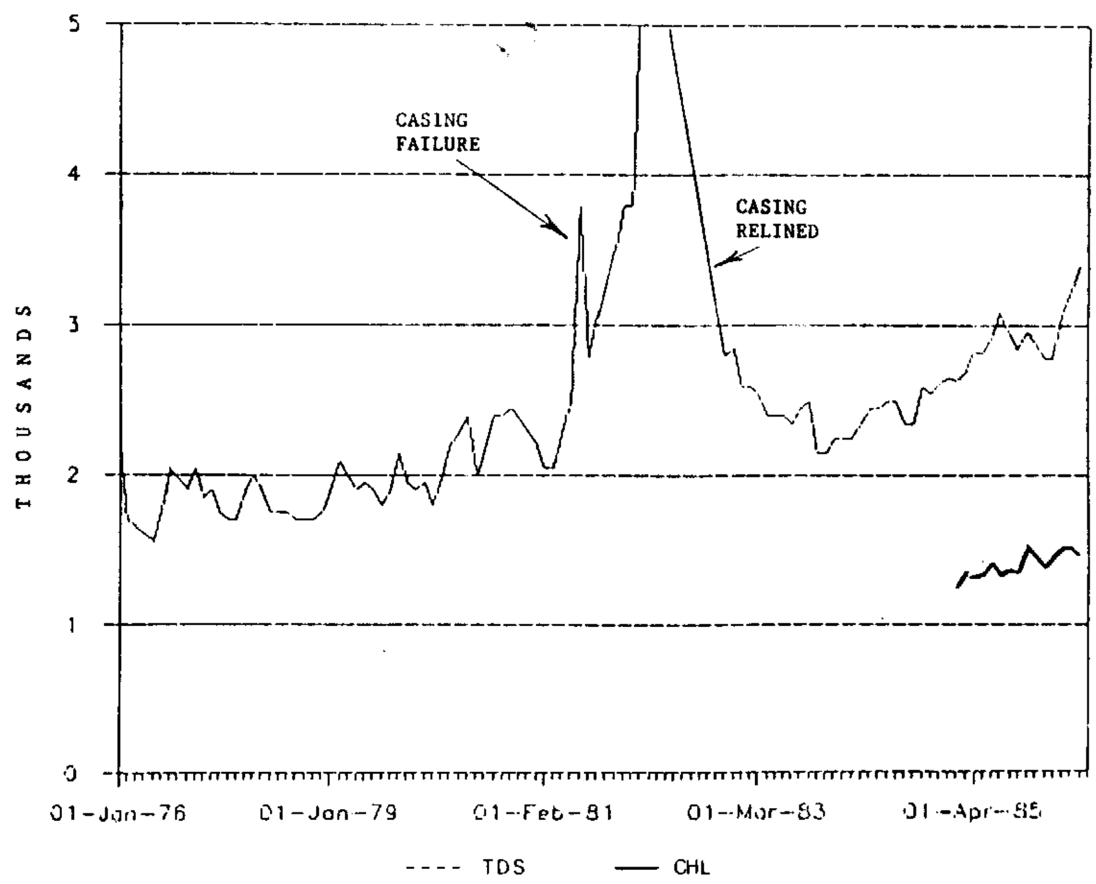

FIGURE 1. The Island Water Association, Inc.
Well Hawthorne 9

A combined program of geophysical logging and downhole sampling identified problems in some wells. Water quality declines were determined to result from loss of casing integrity or aquifer deterioration. Only metal cased wells experienced casing-related failures. The most dramatic was the failure of Well H9 resulting from corrosion induced holes at 45 to 60 feet. Some water quality decline can be caused by annular movement in poorly cemented rotary wells or driven wells.

In some wells, the water quality decline was due to actual degradation of the resource. Samples were collected from various depths. The open hole portion of some wells had deteriorated the entire length. One well, H5, showed deterioration of only a discrete zone at the base of the well.

It was decided to isolate the contaminating zones from the still desirable production zone. This was done by inserting and pressure grouting a PVC liner inside the metal casing. Well H5 was also partially backfilled when being relined. The water quality of H5 improved, but the well yield was reduced.

Three metal cased wells have now been lined. These well rehabilitations have helped extend the life of the ED plant using the existing wells. Implementation of the improved monitoring system also allowed identification of wells which were being overpumped. Reducing withdrawals of these wells has extended their usable time. Finally, new exploratory drilling northwest from the treatment plants have located better quality water in both the deeper Hawthorn and shallower Suwannee aquifers. All these factors have contributed to an improvement of the existing ED raw water sources and predictions for future sources.

The improved monitoring program allows better identification of aquifer- and well-related problems. It also permits better management of the groundwater resource. The monitoring of quality, amount, and pumping levels identified serious and different problems in the Suwannee wells.

SUWANNEE WELLS

Problems associated with the Hawthorn wells were water quality related. After less than a year of operation, the first Suwannee production well (S1), developed a new problem. This was not identified until after the well pump overheated and seized during normal operation.

At that time, monitoring of the new Suwannee production wells was for only water quality. After pulling the pump, testing of the well showed the specific capacity had declined to less than 5 gpm/ft. The initial specific capacity of the well was 8.6 gpm/ft in January, 1979.

A new monitoring program was initiated for all IWA production wells after the failure of S1. Starting in mid-1983, all Hawthorn and Suwannee production wells were monitored for water quality, pumping levels, and discharge. Hawthorn production wells showed no decline in specific capacity. All Suwannee production wells have shown a rapid decline in specific capacity. Figure 2 is a plot of specific capacity versus time for S1. This regular and rapid decline occurs in all Suwannee production wells.

The declining pumping level can cause increased power costs, increased saltwater intrusion potential, increased equipment wear, and inadequate suction pressure at the high pressure pumps. The probable cause of the pumping level declines in the Suwannee production wells was thought to be carbonate incrustation. Due to the pressure differential caused by pumping from carbonate wells, CO_2 is released from the water. This can result in the precipitation of carbonates, principally calcium carbonate ($CaCO_3$) [Water Well Technology, 1973]. This precipitation occurs most favorably in the well intake area. This is the area of maximum pressure differential.

The traditional method of treating carbonate incrustation is to acidize the well. This is commonly done by implacing a volume of acid into the producing section of the well. After agitation, the well is then pumped until it is clean. This treatment is often effective, but is relatively expensive. After finding that the Suwannee production wells required rehabilitation every 8 to 12 months, a more effective treatment was sought.

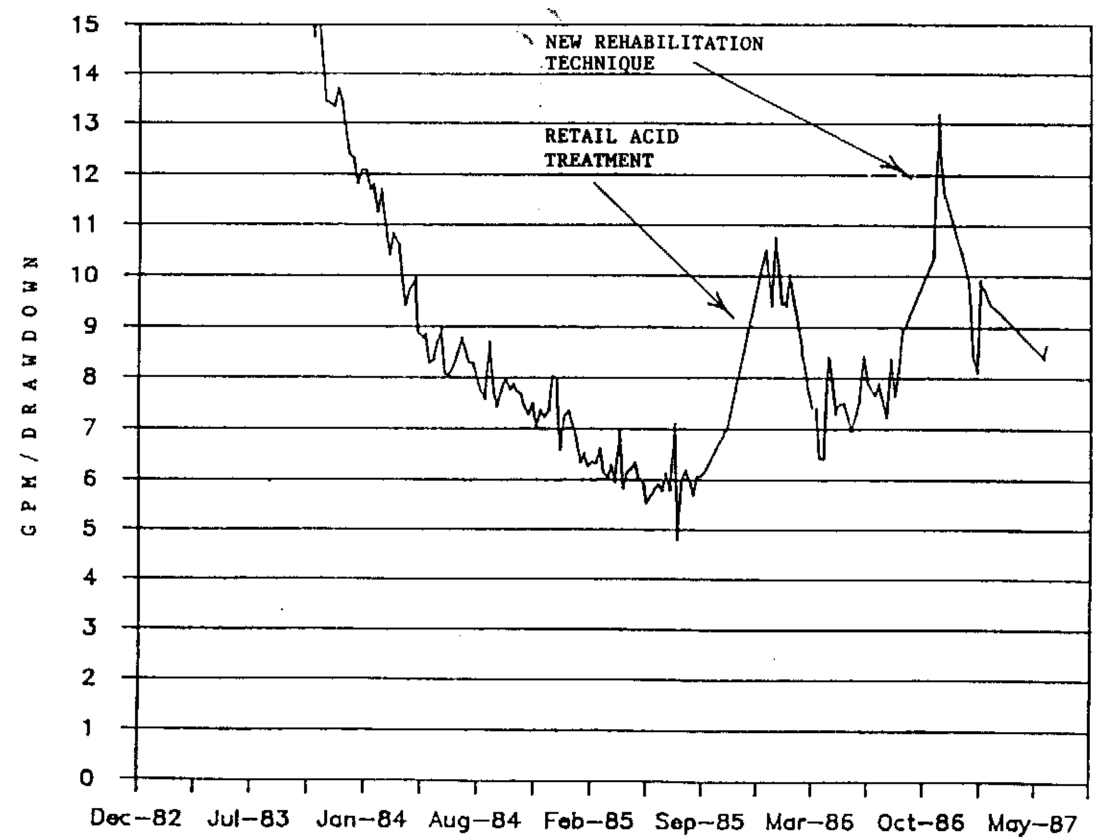

FIGURE 2. The Island Water Association, Inc.
Well Suwannee 2

Well S2 experienced declining pumping levels, as did the other wells. A new treatment method was applied. The well was under-reamed. This is a process where an expandable drilling bit is lowered through the casing and then is engaged to cut 4 additional inches from the well bore. This treatment was ineffective, demonstrating that the precipitation was occurring further into the formation than could be penetrated by the bit.

A regular program of retail acid treatments was again implemented after the ineffective under-reaming. In 1986, Richard Derowitsch of IWA, implemented a new rehabilitation technique. This method was much more convenient and much less expensive.

The typical well acidization requires the removal of the pump column and implacement of large quantities of acid. The Derowitsch method requires only a permanently installed drop pipe in the well and the introduction of CO_2 gas into the well via the pipe. This method is obviously much less expensive, and test results have exceeded previous rehabilitation methods. This method requires no expensive well pump installation and only $200.00 worth of materials. The treatment does take 2 to 3 weeks, during which the well must be offline. The cost of this rehabilitation method is less than 5 percent the expense of the traditional well acidization operation. This is a savings of $75,000.00 per year for IWA. IWA now uses an integrated monitoring system for all Hawthorn and Suwannee production wells. Pumping levels, water quality, and withdrawal are monitored on all wells. The quality and quantity of feedwater, due to the above described monitoring and rehabilitation efforts, is meeting or exceeding treatment plant needs.

PRETREATMENT SYSTEM

The feedwater contains 4 ppm of dissolved hydrogen sulfide which is removed through a combination of deaeration and chlorination. The deaerator is a natural draft gravity cascade type. The water first flows through the deaerator and then collects in a prestressed concrete reservoir. Approximately 1 ppm of hydrogen sulfide is removed in the deaerator. Five ppm of chlorine is injected into the reservoir to oxidize the remaining hydrogen sulfide.

A considerable amount of sludge accumulates in the bottom of the tank and periodic cleaning is required. Water from the reservoir is pumped to the dechlorinators. The dechlorinators have a graded support of rock and sand and a 24-inch bed of activated carbon. The dechlorinators remove any residual chlorine and act as a preliminary filler. The water is then polished in two cartridge filter vessels each containing 78 cartridges with a particular retention size of 5 microns.

The dechlorinator piping was a major source of maintenance. Excessive corrosion caused many leaks and valve failures. In 1979, the entire dechlorinator piping system was replaced with FRP and PVC piping. All valves were replaced with corrosion resistant valves. Since that time, maintenance costs have been minimal.

The hydrogen sulfide fumes from the deaerator form sulfuric acid which is causing considerable localized corrosion. IWA is currently investigating the possibility of bypassing the deaerator and removing all the hydrogen sulfide through a combination of super chlorination and contact with the activated carbon in the dechlorinators. It is anticipated that this will eliminate the corrosion problem but increase operating costs.

THE ELECTRODIALYSIS PLANT

The original plant was installed in 1973 and was arranged in eight banks of three stages each. It had a capacity of 1.2 mgd and was designed to operate with a feed TDS of 2,900. Two years later, another six banks were added, bringing the capacity to 2.1 mgd. In 1979, a 70,000 GPD Aquamite X EDR unit was installed as part of a joint R & D project between IWA and Ionics.

By 1982, the Aquamite unit was producing water at a DC power consumption of 3.2 kWh/1,000 gallons when compared with the old banks at 6.5 kWh/1,000 gallons. Ionics attributed this increased efficiency to a new type of anion membrane. Since that time, nine banks have been upgraded with these new anion membranes.

Four of the remaining banks were built up using the best of the old membranes. The performance of these banks is less than that of the refurbished banks and they are used sparingly. The remaining bank is disassembled and will require new membranes and spacers to be placed on stream.

When these membranes were replaced, IWA estimated their life to be five years. This was based primarily on similar experience with RO membranes. Since that time, IWA has been unable to document any decline in the membranes. Certainly part of this is attributable to the limited use of the plant and the quality of the water being produced. The plant is currently producing about 200,000,000 gallons of 800 TDS water annually. IWA now estimates the membrane life to be 15 years.

A major quality control problem was discovered when Ionics switched from a die cut spacer to one of a molded design. As soon as the problem was apparent, Ionics replaced the problem spacers with the original die cut ones and the spacer problem has been eliminated.

Corrosion was a major problem in the plant. The normally humid environment was worsened by the presence of hydrogen sulfide fumes. Many corroded steel components were replaced with new stainless steel pieces. Some large castings were sandblasted and coated with glass epoxy. Many junction boxes were replaced with weather-tight boxes. Splintered wood decking was replaced with fiberglass grating. The rectifiers and the majority of the electrical components were enclosed in an air conditioned room. An overhead crane was installed to ease stack maintenance.

A major preventative maintenance program was initiated. Components are kept clean and painted. Critical bolts are checked for proper torque. Electrical connections are cleaned and checked periodically.

Two of the unidirectional banks were converted to reversal banks similar to the experimental Aquamite X unit. The reversal process switches the DC polarity every 15 minutes, changing the dilute stream to a concentrate stream and vice versa. Automatic valves simultaneously switch the flows. The reversal process is intended to remove substances which would normally tend to coat the membranes, thus extending membrane life and reducing maintenance. IWA spent $28,000 to convert the two banks.

The IWA ED plant is experiencing minimal maintenance on both the unidirectional and EDR banks, therefore, the extra expense and maintenance of the reversal components did not warrant converting the remaining banks to EDR.

POST-TREATMENT

The original post-treatment system consisted of a silo and a worm-gear vibrating feeder for the addition of powered caustic soda for pH control. Again, the high humidity caused many problems with this unit. The powdered caustic soda tended to bridge and cake, making it difficult to maintain a consistent feed rate. The entire unit was replaced in 1979 with a storage tank and feed system using liquid sodium hydroxide. The new system provides more accurate pH control with less maintenance at a lower cost.

Three ppm of Virchem (trade name), a zinc orthophosphate, are added to the finished water for corrosion control.

OPERATING COSTS

The product waters from the RO and the ED plants are blended prior to distribution. This gives IWA the ability to manufacture higher TDS water in the ED plant for blending with the lower TDS RO water. The ED process has the advantage of being able to adjust the degree of desalination desired. The cost will increase as the amount of desalination increases. The current operating mode is to produce 70 TDS water in the RO plant and 800 TDS water in the ED plant. One could argue that it is not fair to compare the RO costs against the ED cost because of the vast difference in the amount of minerals removed. The other side of that argument is that IWA sells its water by the gallon and gets the same price for the ED water as for the RO water. Current operating costs are shown in Table 2.

Table 2

CURRENT OPERATING COSTS, FIRST SIX MONTHS, 1987

Chemicals	$/K Gal		
Sulfuric Acid	.020		
Sodium Hydroxide	.018		
Chlorine	.021		
Virchem	.021		
Muriatic Acid	.006		
Peroxide	.017		
Soda Ash	.006		
		Subtotal	.109
Electrical			
Plant	.397		
Wells	.107		
		Subtotal	.504
Other			
Repair Parts	.133		
Filters	.015		
Membrane Replacement	.041		
Carbon Replacement	.019		
		Subtotal	.208
		TOTAL	.82

ADVANTAGES TO IWA

1. Silica is not removed by electrodialysis; therefore, it does not concentrate in the brine and create a scaling problem. In addition, the ED membranes are tolerant of high iron levels. This allows IWA the ability to use wells that would otherwise have to be abandoned due to high silica and iron levels.

2. The ED membranes are also tolerant of high chlorine levels, up to 10 mg/liter for short periods. This eliminates the danger of harming the membranes with an accidental dose of chlorine. The wells and well line must be superchlorinated after repairs. There is always the possibility of introducing chlorine into the plant.

3. The flexibility of the ED process allows IWA to conserve energy and make high TDS water for blending, or potable water can be produced by simply increasing the voltage.

4. A stack can be disassembled, the individual membranes removed, and manually cleaned. Individual membranes can be replaced without discarding the entire stack.

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A CASE HISTORY OF REVERSE OSMOSIS
AT CAPE CORAL, FLORIDA

by

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DESALINATION IN SOUTH FLORIDA
August 21, 1988

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INTRODUCTION

In 1970, Cape Coral was incorporated with 11,470 people. By 1980, the population had increased to 32,103 (almost 170 percent). That growth continued over the next six years with more than a 70 percent increase. Of course, one of the most prevailing problems, not only for Cape Coral but all communities, is how to provide a potable water supply. This problem is magnified with the growth rates all of Florida is experiencing.

Even though Cape Coral is surrounded by the Gulf of Mexico, Caloosahatchee River, and Pine Island Sound, their seawater characteristics make them a last resort for a raw water supply. Therefore, we have utilized groundwater located in the Hawthorn aquifer.

When the City purchased the utility department, it came with a 2 million gallons per day (mgd) lime softening plant. The plant was fed by wells located in the Upper Hawthorn (100 to 200 feet deep).

Through uncontrolled tapping of this relatively freshwater source in the 1960's and 1970's, the static levels began to drop. This had the potential to cause saltwater intrusion and ruin the aquifer for future use. Therefore, in 1976, the City took a bold step and built a reverse osmosis (RO) plant. The plant tapped the brackish groundwater in the Lower Hawthorn aquifer. The wells are 700 to 900 feet deep with chlorides of 600 to 800 mg/l.

The design was for a 3 mgd plant that was expandable to 5 mgd. Dow brackish water membranes were installed operating at a feed pressure of 450 pounds per square inch (psi) and a 65 percent recovery.

In the first few years the plant operated at only 30 percent of capacity. This sounds low but actually allowed the operators and management to learn how to operate the plant and the bugs to be worked out of the system. As growth continued, it was necessary to expand the plant to 5 mgd capacity in 1979. That was done by Water Services of America who used Du Pont membranes. They operated at a feed pressure of 400 psi with a recovery of 75 percent. Four wells were also added to provide the additional raw water. They tapped the same Lower Hawthorn aquifer.

The expansion was operated at a lower feed pressure which helped to reduce the energy usage plus it produced more water by operating at the higher recovery rate. Working with Dow, it was determined that their membranes could also be operated in the same fashion. Therefore, the City went through a pump destaging program. This consists of removing a bowl and impeller from the high pressure pumps to achieve the pressure reduction. While doing that, we also increased the recovery to 75 percent. This not only unified system operations but showed how easy RO can adapt to advancements in technology.

In 1984, the City began to consider a membrane replacement program. Before all the details could be worked out, the system began to experience major problems. Rapid losses of production and increases in differential pressures and salt passage were occurring. The probable causes would not be determined till a later date but we could ill afford to lose the RO plant.

We went out on an emergency basis to install new membranes. With the help of Mr. Ian Watson (Rostek Services), we put together a set of specs and contracted with Water Services of America for the work.

Because of the preliminary studies done with the re-membraning program, we knew we could use the new low-pressure membranes. So they installed 240 low-pressure Dow membranes. They could operate at a feed pressure of 250 psi with a 75 percent recovery. Once again we went through a pump destaging program to achieve the energy savings possible with the new lower pressure membranes.

During the installation we began to determine the probable causes for the membrane failure. They were unreliable chemical supplies, meter inaccuracies, and improper well field construction.

The unreliable chemical supplies refers to the sodium hexametaphosphate we were using as our antiscalant. Looking through the daily records, we noticed that on days of similar flows, the amount of hex used varied from 10 pounds to 100 pounds. The test we used to determine the feed parts per million (ppm) was based on the amount of phosphate in the water. We took for granted that the quality was stable. There were no double checks on the system. Since we did not have the tools in place that could check the dosage rate every minute, the dosage rate in parts per million was fluctuating. This meant that we could, with no knowledge, be overdosing or underdosing.

Metering inaccuracies were found during the replacement program. We discovered the numbers used to calibrate the meters were incorrect. The numbers were derived from the wall thickness of the pipe. We were given numbers for cast iron pipe instead of the stainless steel pipe we had. This difference would throw off the conversions; therefore, operating the membranes at lower or higher recoveries.

The combination of varying recoveries and unstable scale inhibitor dosages is the best probable cause for the quick and rapid scaling that we had.

Could these problems have been avoided? Possibly, with the proper data management system, a series of checks and balances could have been in place that might have prevented the catastrophic emergency. The City has since developed our own data management programs. The following is a brief explanation of the various programs and their functions.

DATA MANAGEMENT PROGRAMS

RAW WATER SUPPLY PROGRAM

Our raw water supply program has the monthly chemical, static level, and pumping data of our 22 supply wells; information from the 8 Lower Hawthorn monitoring wells; and static level information from 18

Upper Hawthorn wells (see Figures 1 and 2). These data are then transferred to compliance files that include all the data from the first records.

REJECT MONITORING PROGRAM

The reject monitoring program includes all the required data for compliance with our DER and EPA permits. With two reject streams from the facility and two permits for each of the streams, the data can get easily scrambled. Figure 3 shows the output of the reject monitoring program. This form has been accepted by DER for reporting purposes.

DAILY OPERATIONS PROGRAM

Our daily operation program (we call our totalizer) includes all the necessary data for the day-by-day operations of the facility. The information is gathered throughout the day and entered in the computer every night, then transferred to their required places in the program. The program separates the data so each plant is treated individually, or combined when applicable, such as with our DER monthly report. The page that could have helped with the hex problem is the daily chemical sheet (see Figure 4).

As you can see, the page gives you daily usage, bulk tank totals, and dosage in ppm. Even though the flows may fluctuate, the totals should all work out. In addition, at the end of the month we take bulk tank totals or inventory readings and compare those with the daily readings (see Figure 5). They will never be exactly the same but if they are within a certain percentage it is acceptable.

MEMBRANE WARRANTY ADHERENCE AND TRACKING PROGRAMS

The membrane warranty adherence and membrane tracking programs are for the treatment process. It takes data gathered by the operators on the skids and individual membranes so we can check to make sure the system is operating properly.

Figure 6 is the output sheet for the warranty adherence program. The data shown are derived from eight numbers gathered on each skid then used to give us the remaining information. These data are then

RO WELLS ANALYSIS FOR: BLANK

WELL	pH	TOT ALK	TOT HARD	CAL HARD	MAG HARD	CHLOR	TDS	COND	COLOR	FLOR	H_2S	TURB	PUMP LEVEL	PUMP RATE	TOTAL PUMPAGE	STAT LEVEL
RO-01	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	10.13
RO-02	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	10.11
RO-03	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	10.12
RO-04	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	10.01
RO-05	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	10.29
RO-06	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	0.00
RO-07	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	9.97
RO-08	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	9.60
RO-09	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	8.76
RO-10	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	10.08
RO-11	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	9.03
RO-12	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	11.11
RO-13	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	10.54
RO-14	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	11.36
RO-15	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	12.59
RO-16	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	9.17
RO-17	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	9.70
RO-18	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	11.12
RO-19	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	10.67
RO-20	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	11.70
RO-21	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	9.93
RO-22	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	9.50
AVG	0.00	0	0	0	0	0	0	0	0	0.00	0.0	0.00	0	0	0	-10

LINE WELLS

WELL	STATIC LEVEL
L-01	1.57
L-03	4.89
L-04	7.49
L-05	8.96
L-06	12.25
L-07	12.30
L-08	12.18
L-09	11.82
L-10	12.80
L-11	9.88
L-12	10.13
L-13	11.41
L-14	10.94
L-15	11.62
L-16	11.96
L-17	13.37
L-18	11.70
U-01	10.18
U-02	9.45
U-03	9.04

OBSERVATION WELLS

WELL	STATIC LEVEL	CHLOR	TDS	COND
OW-A	8.93	0	0	0
OW-B	8.23	0	0	0
OW-C	9.20	0	0	0
OW-D	12.53	0	0	0
OW-E	11.54	0	0	0
OW-F	9.70	0	0	0
OW-G	11.64	0	0	0
OW-H	9.96	0	0	0
OW-I	0.00	0	0	0
OW-J	9.62	0	0	0
OW-K	10.05	0	0	0
OW-L	8.22	0	0	0

NOTE: STATIC LEVELS ARE ADJUSTED ACCORDING TO INDIVIDUAL NGVD's.

FIGURE 1 Raw Water Supply Data Output

OBSERVATION WELL "A"

LOCATION: CAPE CORAL PKWY & SANDS BLVD
CASING DEPTH: 433'
TOTAL DEPTH: 520'　　NGVD: 8.93
DIAMETER: 4"　　STATE CORD: N 810100
YEAR DRILLED: 1985　　E 409340

	STAT LEVEL	CHLORIDE	TDS	COND
JAN 1985	0	0	0	0
FEB	0	0	0	0
MAR	0	0	0	0
APR	0	0	0	0
MAY	0	0	0	0
JUN	0	0	0	0
JUL	-11.07	0	0	0
AUG	-11.57	0	0	0
SEP	-11.37	0	0	0
OCT	-12.07	0	0	0
NOV	-11.57	540	1413	2260
DEC	-10.07	560	1406	2250
JAN 1986	-10.57	340	1394	2230
FEB	-10.57	540	1462	2340
MAR	-11.07	540	1413	2260
APR	-10.07	560	1438	2300
MAY	-9.57	560	1493	2390
JUN	-10.07	540	1481	2370
JUL	-11.07	560	1469	2350
AUG	-12.07	540	1394	2230
SEP	-12.07	580	1469	2350
OCT	-11.57	560	1431	2290
NOV	-10.57	540	1450	2320
DEC	-10.57	520	1406	2250

OBSERVATION WELL "B"

LOCATION: CAPE CORAL PKWY & SKYLINE BLVD
CASING DEPTH: 495'
TOTAL DEPTH: 600'　　NGVD: 8.23
DIAMETER: 4"　　STATE CORD: N 810160
YEAR DRILLED: 1985　　E 503382

	STAT LEVEL	CHLORIDE	TDS	COND
JAN 1985	0	0	0	0
FEB	0	0	0	0
MAR	0	0	0	0
APR	0	0	0	0
MAY	0	0	0	0
JUN	0	0	0	0
JUL	-11.27	0	0	0
AUG	-10.27	0	0	0
SEP	-11.27	0	0	0
OCT	-13.27	0	0	0
NOV	-11.27	1340	2744	4390
DEC	-9.77	1620	3444	5510
JAN 1986	-8.77	1640	3481	5570
FEB	-8.77	1700	3675	5880
MAR	-9.27	1640	3631	5810
APR	-9.77	1700	3594	5750
MAY	-8.27	1680	3800	6080
JUN	-9.77	1680	3713	5940
JUL	-10.27	1660	3713	5940
AUG	-10.77	1660	3481	5570
SEP	-10.77	1700	3750	6000
OCT	-9.27	1700	3681	5890
NOV	-10.27	1600	3675	5880
DEC	-9.27	1700	3487	5500

FIGURE 2　Monitoring Well Data Output

JUNE 1987

CITY OF CAPE CORAL REJECT ANALYSIS REPORT

HYDRANAUTICS REJECT

DER PERMIT # IC36890607

DAY	FLOW (X1000)	pH	TOT HARD	CHLOR	TDS	TEMP	DO	CL2	H2S
1	579	6.90	2376	2400	6991	80	0	0	4.40
2	665	7.09	2520	2500	7451	80	0	0	5.20
3	645	7.02	2480	2700	7600	80	0	0	4.20
4	592	7.02	2540	2560	7385	80	0	0	5.40
5	691	6.77	2440	2480	7242	81	0	0	5.00
6	681	6.90	2320	2400	6634	80	0	0	5.20
7	675	6.81	2440	2100	6546	81	0	0	5.60
8	678	7.00	2360	2100	6578	81	0	0	5.40
9	236								
10	557	6.90	2400	2400	7139	80	0	0	5.40
11	650	6.93	2440	2400	7170	80	0	0	5.20
12	641	6.78	2312	2400	6596	81	0	0	4.80
13	600	6.84	2400	2500	7385	80	0	0	5.20
14	675	6.88	2528	2560	7319	81	0	0	5.20
15	673	6.81	2558	2560	7242	80	0	0	5.20
16	645	6.93	2572	2600	7457	80	0	0	6.00
17	584	6.93	2452	2400	7140	82	0	0	5.00
18	662	6.95	2392	2240	6575	80	0	0	5.40
19	647	6.95	2340	2120	6553	80	0	0	5.20
20	664	6.85	2240	2200	6353	81	0	0	4.40
21	690	7.00	2176	2200	6224	80	0	0	5.40
22	682	6.77	1896	1800	5392	81	0	0	6.00
23	599	6.96	2100	2000	6202	80	0	0	4.40
24	552	6.83	2100	2240	6539	81	0	0	5.60
25	555	6.94	2400	2300	7019	82	0	0	6.60
26	686	6.92	2320	2240	6683	82	0	0	5.20
27	684	6.85	2496	2400	6855	82	0	0	5.20
28	706	6.98	2312	2260	6497	82	0	0	6.40
29	604	6.92	2432	2600	6318	82	0	0	4.20
30	556	6.97	2240	2300	6610	82	0	0	5.00
31									
MIN	236	6.77	1896	1800	5392	80	0	0	4.2
MAX	706	7.09	2572	2700	7600	82	0	0	6.6
AVG	625.2	6.9186	2373.4	2347.1	6831.6	80.758	0	0	5.2344

DOW REJECT

DER PERMIT # IO36-04435

DAY	FLOW (X1000)	pH	TOT HARD	CHLOR	TDS	TEMP	DO	CL2	H2S
1	1182	6.28	1820	1800	5287	80	0	0	6.00
2	1350	6.45	1680	1800	5315	81	0	0	3.80
3	1301	6.52	1672	1800	5245	80	0	0	5.80
4	818	6.43	1740	1820	5428	80	0	0	4.80
5	979	6.45	1660	1800	5174	81	0	0	5.20
6	1149	6.47	1620	1660	5132	81	0	0	4.60
7	965	6.52	1656	1800	5217	80	0	0	4.20
8	960	6.44	1560	1740	5203	81	0	0	3.00
9	1276	6.49	1744	1860	5357	80	0	0	4.00
10	920	6.40	1716	1820	5364	80	0	0	4.80
11	637	6.67	1864	2100	5766	80	0	0	6.00
12	476	6.35	1852	2100	5787	80	0	0	5.20
13	666	6.40	1840	2080	5773	81	0	0	4.40
14	487	6.42	1760	1900	5407	80	0	0	5.00
15	604	6.39	1764	2040	5555	80	0	0	5.40
16	780	6.28	1680	1700	5132	80	0	0	5.00
17	619	6.43	1636	1600	5626	80	0	0	5.40
18	846	6.29	1700	1800	5372	80	0	0	5.20
19	843	6.35	1640	1760	5005	81	0	0	5.20
20	674	6.34	1750	1900	5301	81	0	0	5.20
21	512	6.34	1800	2120	5681	81	0	0	3.40
22	660	6.41	1732	1900	5315	80	0	0	4.20
23	1063	6.34	1704	1900	5293	81	0	0	4.80
24	1139	6.42	1760	1940	5322	82	0	0	4.00
25	1122	6.33	1740	1840	5294	82	0	0	5.20
26	884	6.47	1720	2000	5372	82	0	0	5.20
27	713	6.37	1768	1900	5322	81	0	0	4.40
28	447	6.31	1872	1900	5230	82	0	0	3.00
29	345	6.34	1704	1940	5264	82	0	0	4.00
30	679	6.42	1840	1900	5273	82	0	0	5.20
31									
MIN	345	6.28	1560	1600	5009	80	0	0	3
MAX	1350	6.67	1800	2120	5787	82	0	0	6
AVG	836.066	6.404	1730.4	1880	5337.7	80.733	0	0	4.6933

SUPPLEMENTAL DATA (HYDRANAUTICS REJECT)

DAY	PO4	TSS	FLOR	GROSS ALPHA	GROSS BETA	PHOTON RADIO	R226	R228
11	0	4	7.202	0	30	ND	0	0

SUPPLEMENTAL DATA (DOW REJECT)

DAY	PO4	TSS	FLOR	GROSS ALPHA	GROSS BETA	PHOTON RADIO	R226	R228
11	0	3	0.500	0	32	ND	0	0

HYDRANAUTICS REJECT

EPA PERMIT # FL0040000

ITEM	MIN	AVG	MAX	ITEM	MIN	AVG	MAX
TSS	XXXXX	4	XXXXX	FLOW	236	625.2	706
TOTAL PO4	XXXXX	0	XXXXX	FL	XXXXX	7.202	XXXXX
pH	6.77	6.92	7.09				

DOW REJECT

EPA PERMIT # FL0034932

ITEM	MIN	AVG	MAX	ITEM	MIN	AVG	MAX
TSS	XXXXX	3	XXXXX	FLOW	345	836.06	1350
TOT PO4	XXXXX	0	XXXXX	CHLOR	1600	1880	2120
pH	6.28	6.404	6.67				

FIGURE 3 Reject Monitoring Program Output

CHEMICALS USED
JUNE 1987

DOW

	ACID				CAUSTIC				FLOC-CON			
DAY	BEGIN BAL.		5609		BEGIN BAL.		2986		BEGIN BAL.		430	
	DAILY	DELIV	RUNN	PPM	DAILY	DELIV	RUNN	PPM	DAILY	DELIV	RUNN	PPM
1	438	0	5171	168	105	0	2881	37	22	0	408	5.31
2	519	0	4652	174	126	0	2755	38	26	0	382	5.46
3	537	0	4115	187	123	0	2632	39	22	0	360	4.81
4	283	0	3832	156	59	0	2573	30	15	0	345	5.20
5	357	0	3475	164	75	0	2498	31	18	0	327	5.18
6	411	0	3064	162	96	0	2402	34	21	0	306	5.19
7	348	0	2716	163	70	0	2332	30	17	0	289	4.99
8	457	0	2259	213	78	0	2254	33	17	0	272	4.98
9	477	3269	5051	169	128	0	2126	41	24	0	248	5.35
10	311	0	4740	150	99	0	2027	43	20	0	228	6.07
11	216	0	4524	154	35	0	1992	23	11	0	217	4.93
12	172	0	4352	164	22	0	1970	19	8	0	209	4.78
13	227	0	4125	153	32	0	1938	20	11	0	198	4.67
14	178	0	3947	165	17	0	1921	14	8	0	190	4.66
15	202	0	3745	152	27	0	1894	19	10	0	180	4.72
16	305	0	3440	175	30	0	1864	16	15	550	715	5.40
17	229	0	3211	164	30	0	1834	19	11	0	704	4.95
18	314	0	2897	168	60	0	1774	29	14	0	690	4.69
19	267	0	2630	143	85	0	1689	41	16	0	674	5.36
20	245	0	2385	164	30	0	1659	18	9	0	665	3.77
21	240	0	2145	210	24	0	1635	19	10	0	655	5.49
22	284	3099	4960	193	35	0	1600	21	13	0	642	5.55
23	367	3170	7763	159	95	0	1505	37	19	0	623	5.15
24	431	0	7332	172	113	0	1392	41	21	0	602	5.25
25	446	0	6886	179	117	0	1275	43	22	0	580	5.54
26	349	0	6537	179	104	0	1171	48	18	0	562	5.80
27	267	0	6270	172	42	0	1129	24	13	0	549	5.24
28	211	0	6059	215	23	0	1104	21	8	0	541	5.12
29	125	0	5934	162	18	0	1088	21	6	0	535	4.88
30	321	0	5613	211	31	0	1057	18	12	0	523	4.95
31												
TOT	9534	9538			1929	0			457	550		
INV	9538				1458				485			
DIF	-4				471				-28			

FIGURE 4 Daily Chemical Usage Output Sheet

JUNE 1987

*************************** DOW ***************************

CHLORINE:

CARRY OVER	6454
AMOUNT RECIEVED	12000
SUB-TOTAL	18454
AMOUNT USED	10112
ON HAND	8342
PPM	5.92

ELECTRIC:

END READ:	9279
START READ:	8772
USED:	507
DEMAND:	1.94

ANTISCALANT:

CARRY OVER	430
AMOUNT RECIEVED	550
SUB-TOTAL	980
AMOUNT USED	485
ON HAND	495
PPM	4.70

CAUSTIC:

CARRY OVER	2986
AMOUNT RECIEVED	0
SUB-TOTAL	2986
AMOUNT USED	1458
ON HAND	1528
PPM	23.73

SULFURIC ACID:

CARRY OVER	5609
AMOUNT RECIEVED	9538
SUB-TOTAL	15147
AMOUNT USED	9538
ON HAND	5609
PPM	147.26

*************************** HYDRANAUTICS ***************************

ANTISCALANT:

CARRY OVER	600
AMOUNT RECIEVED	550
SUB-TOTAL	1150
AMOUNT USED	530
ON HAND	620
PPM	4.70

CAUSTIC:

CARRY OVER	1381
AMOUNT RECIEVED	3400
SUB-TOTAL	4781
AMOUNT USED	2162
ON HAND	2619
PPM	29.71

SULFURIC ACID:

CARRY OVER	6667
AMOUNT RECIEVED	6621
SUB-TOTAL	13288
AMOUNT USED	7871
ON HAND	5417
PPM	111.29

FIGURE 5 Inventory Analysis Sheet

June 1987

SKID	DAY	1st STGE FEED PSI	2nd STGE FEED PSI	BRNE PSI	BRNE TO DRAN PSI	PROD TO STOR PSI	TOTL PROD FLOW GPM	2nd PROD FLOW GPM	1st PROD FLOW GPM	BRNE FLOW GPM	BRNE COND mo/cm	PROD COND mo/cm	FEED COND mo/cm	1st STGE DLTA °P	2nd STGE DLTA °P	TRAN MEMB PSI	SALT PASS %	RECOVERY by FLOW %	RECOVERY by COND %	1st AVG INT FLOW	2nd AVG INT FLOW	SILT DENS PRE	SILT DENS POST	TURB NTU
A	1	260	205	141	25	13	300	89	211	100	7060	271	2430	55	64	247	12.0	75.0	68.4	18.41	25.04	0.53	0.61	0.11
A	2	260	203	138	23	13	300	90	210	100	7000	280	2350	57	65	247	12.3	75.0	69.3	18.44	25.03	0.39	0.70	0.11
A	3	260	203	138	23	13	300	90	210	100	7280	290	2390	57	65	248	12.1	75.0	70.0	18.44	25.03	0.42	0.60	0.10
A	4	260	203	139	15	9	310	90	220	102	7230	283	2430	57	64	251	11.6	75.2	69.1	18.88	25.68	0.30	0.50	0.11
A	5	260	206	150	21	12	300	91	209	100	7080	274	2330	54	56	248	11.8	75.0	69.8	18.47	25.03	0.40	0.35	0.12
A	6	260	203	144	19	12	300	89	211	100	6880	278	2250	57	59	248	12.4	75.0	70.1	18.41	25.04	0.32	0.60	0.11
A	7	OFF																						
A	8	260	211	156	11	8	280	91	189	93	7470	313	2300	49	55	252	13.6	75.1	72.2	17.41	23.28	0.41	0.49	0.13
A	9	260	206	154	11	13	300	90	210	100	7030	298	2390	54	52	248	12.5	75.0	68.9	18.44	25.03	0.36	0.74	0.09
A	10	260	205	145	17	11	300	90	210	100	7390	287	2430	55	60	250	11.8	75.0	69.8	18.44	25.03	0.37	0.60	0.12
A	11	OFF																						
A	12	OFF																						
A	13	OFF																						
A	14	OFF																						
A	15	260	205	143	11	8	300	90	210	100	7740	334	2550	55	62	253	13.1	75.0	70.1	18.44	25.03	0.41	0.59	0.14
A	16	260	204	145	16	10	300	92	208	100	7130	280	2310	56	59	251	12.1	75.0	70.4	18.50	25.02	0.67	0.45	0.11
A	17	OFF																						
A	18	260	208	153	25	13	300	90	210	100	7280	298	2450	52	55	247	12.2	75.0	69.2	18.44	25.03	0.30	0.34	0.19
A	19	OFF																						
A	20	OFF																						
A	21	OFF																						
A	22	OFF																						
A	23	260	206	152	24	13	300	90	210	100	7330	297	2420	54	54	247	12.3	75.0	69.8	18.44	25.03	0.32	0.60	0.11
A	24	260	205	150	27	13	300	90	210	100	7310	307	2420	55	55	247	12.7	75.0	69.8	18.44	25.03	0.49	0.67	0.13
A	25	260	206	145	25	13	300	90	210	100	7290	280	2440	54	61	247	11.5	75.0	69.2	18.44	25.03	0.38	0.43	0.10
A	26	260	206	150	11	8	300	91	209	100	7360	287	2450	54	56	252	11.7	75.0	69.4	18.47	25.03	0.33	0.50	0.15
A	27	260	205	145	11	8	300	90	210	100	7310	292	2430	55	60	252	12.0	75.0	69.5	18.44	25.03	0.30	0.46	0.10
A	28	OFF																						
A	29	OFF																						
A	30	OFF																						
MIN		260	203	138	11	8	280	89	189	93	6880	274	2250	49	52	247	11.5	75.0	68.4	17.41	23.28	0.30	0.34	0.09
MAX		260	211	156	27	13	310	92	220	102	7740	334	2550	57	65	253	13.6	75.2	72.2	18.88	25.68	0.67	0.76	0.19
AVG		260	205	146	18	11	299	90	209	100	7245	293	2398	55	59	249	12.2	75.0	69.7	18.41	24.97	0.39	0.55	0.12

FIGURE 6 Warranty Adherence Program Output Sheet

reviewed on a monthly basis, or after automatic transferring, can be reviewed from the first day the system went online. This would have shown the trend analysis that would have given the necessary clues that the system was going down.

As seen in Figure 7, the membrane tracking program shows the performance of each membrane. If the readings on a skid start to decline we can determine if it is a system problem or if individual membranes are going bad.

The plant produces a large amount of data yet it can be easily handled with the proper computer programs. By developing the system ourselves, it allowed us to customize it for RO plants exclusively. We used Lotus 1-2-3 as the base on which we operate all the programs. What this does is make the information easily transferable between programs or to other companies, manufacturers, and suppliers so we can all review and evaluate the system.

FLOW MEASUREMENT

A flow metering problem can be detected with our daily and monthly meter comparison sheets (see Figures 8 and 9). The daily sheet shows the totalized flows on a daily basis in the system and compares them for instant analysis. The monthly sheet takes into account the meter readings from the wells, the skids, and in-plant meters and are compared with the gallon per minute readings multiplied by the readings from the hour meters and given a percentage of accuracy.

The data in Figure 9 allows all flow meters to be compared with all other meters for precision. There should be no lost water in the operation of an RO system; therefore, everything should be accounted for. They will never be 100 percent accurate but when taking into account all the various types, sizes, locations, ages, and accuracies of the meters, if you can get within 97 percent, it is not bad.

If these programs would have been in place, could it have prevented the problem we had? Probably not, because of other circumstances we had, but it could have lessened the impact and not caused an emergency situation.

	PERMEATOR 1 646904						PERMEATOR 2 646897					
MONTH	PROD COND	PERM PSI	PERM 'P	SALT PASS	RECV COND	PIC 'P	PROD COND	PERM PSI	PERM 'P	SALT PASS	RECV COND	PIC 'P
JUL84	170	232	10	7.1	48.5	42	150	213	37	6.9	48.3	23
	150	250		7.1	49.4	40	130	250		6.2	54.9	40
AUG	160	232	10	6.4	46.1	27	160	200	50	6.4	46.1	
	200	235	15	8.7	38.2	25	210	190	60	9.1	50.1	
SEP	150	225	25	6.5	41.1	15	200	227	23	8.7	48.8	17
	130	229	21	6.5	54.1	29	125	229	21	6.3	51.6	29
	150	226	24	6.3	41.6	36	160	231	19	6.7	48.4	41
OCT	150	222	20	6.3	47.1	27	150	226	24	6.3	41.6	31
	150	194	26	7.5	49.0	13	140	196	24	7.0	49.0	15
NOV	142	217	33	7.6	52.4	17	189	223	27	10.2	48.6	23
	155	215	35	6.7		25	137	220	30	6.0	50.7	30
DEC	139	208	42	6.0	54.3	8	148	215	35	6.4	48.7	15
	150	210	40	7.1	55.9	15	183	216	34	8.7	50.0	21
JAN85	163	205	45	7.2	55.8	5	166	210	40	7.3	40.7	10
	154	206	44	6.7	49.1	16	143	208	42	6.2	44.8	18
FEB	179	196	54	7.7	54.4	16	161	200	50	7.0	39.6	20
	131	200	50	5.8	47.9	20	149	205	45	6.6	43.9	25
	160	195	55	7.5	52.3	20	126	205	45	5.7	43.3	30
MAR	167	195	55	7.6	52.9	20	145	208	50	6.6	43.5	25
	170	195	55	8.0	55.7	15	143	200	50	6.7	45.7	20
	169	200	50	8.0	54.8	20	153	200	50	7.2	50.0	20
	230	195	55	10.7	51.0	15	196	200	50	9.1	46.5	20
	183	200	50	8.3	55.5	10	160	205	45	7.3	46.3	15
APR	254	190	60	13.0	58.0	5	227	200	50	11.6	51.8	15
	177	195	57	9.4	50.8	30	145	205	47	7.7	43.1	40
	225	195	55	10.6	56.5	15	175	200	50	8.2	47.8	20
MAY	190	190	60	8.7	55.2	10	203	200	50	9.3	50.2	20
	205	200	50	9.0	49.8	20	185	205	45	8.1	41.7	25
	202	205	55	9.1	55.0	15	176	210	50	8.0	47.9	20
	212	210	50	8.6	53.0	15	187	215	45	7.6	44.6	20
JUN	229	205	55	10.2	59.0	15	196	215	45	8.8	51.0	25
	215	210	50	9.6	54.5	15	190	215	45	8.5	40.0	20
	220	195	55	10.1	55.5	15	198	200	50	9.1	49.3	20
	195	205	45	8.6	53.3	20	173	210	40	7.7	45.7	25
	180	200	50	8.5	51.5	20	168	202	40	7.6	45.3	22

	PERMEATOR 3 646903						PERMEATOR 4 646905					
MONTH	PROD COND	PERM PSI	PERM 'P	SALT PASS	RECV COND	PIC 'P	PROD COND	PERM PSI	PERM 'P	SALT PASS	RECV COND	PIC 'P
JUL84	150	235	15	6.3	43.0	45	140	235	15	5.8	44.3	45
	120	250		5.7	49.0	40	130	250		6.2	52.8	40
AUG	150	190	60	6.0	39.0		150	235	15	6.0	44.7	30
	230	190	60	10.0	45.1		200	235	15	8.7	44.7	25
SEP	160	220	30	7.0	44.3	10	150	230	20	6.5	44.2	20
	120	228	22	6.0	42.7	28	110	229	21	5.5	48.1	29
	150	230	20	6.3	40.0	40	150	228	22	6.3	43.0	38
OCT	160	223	27	6.7	40.1	20	150	223	27	6.3	41.6	28
	134	195	25	6.7	44.7	14	131	195	25	6.6	39.7	14
NOV	135	224	26	7.3	39.8	24	118	221	29	6.3	43.3	21
	134	230	20	5.8	43.4	40	122	220	30	5.3	42.5	30
DEC	158	225	25	6.9	31.6	25	144	212	30	6.3	42.3	12
	151	224	26	7.2	26.1	29	150	214	36	7.1	47.2	19
JAN85	172	221	29	7.6	22.3	21	162	208	42	7.2	45.3	8
	140	220	30	6.4	41.2	30	130	208	42	5.7	24.4	18
FEB	173	213	37	7.5	26.2	33	149	200	50	6.5	43.4	20
	152	220	30	6.7	41.4	40	140	204	46	6.5	33.0	24
	134	220	30	6.1	29.4	45	119	200	50	5.9	43.3	25
MAR	154	220	30	7.0	25.7	45	131	200	50	5.9	42.6	25
	153	220	30	7.2	25.3	40	131	200	50	6.2	44.6	20
	163	210	40	7.7	33.6	30	147	200	50	6.9	46.4	20
	171	220	30	8.0	26.9	40	221	200	50	10.3	45.6	20
	174	220	30	7.9	30.0	30	150	205	45	6.8	44.4	15
APR	240	240	10	12.7	36.2	55	190	200	50	9.7	40.2	15
	204	210	34	10.0	30.8	53	156	200	52	8.3	44.3	35
	180	215	35	8.5	30.4	35	156	200	50	7.3	44.6	20
MAY	185	230	20	8.5	40.0	50	201	200	50	9.2	46.5	20
	199	215	35	8.8	23.6	35	183	200	50	8.1	40.3	20
	192	225	35	8.7	31.5	35	179	210	50	8.1	44.0	20
	190	230	30	8.0	21.8	35	185	215	45	7.5	42.2	20
JUN	204	224	36	9.1	31.1	34	194	217	43	8.7	47.2	27
	210	230	30	9.7	32.4	35	195	212	40	8.7	47.5	17
	225	216	34	10.3	32.0	36	204	200	50	9.4	49.5	20
	205	222	20	9.1	20.3	37	171	200	42	7.6	45.9	23
	205	218	32	9.3	29.0	38	164	202	40	7.4	44.2	22

FIGURE 7 Membrane Tracking Program Output

WELL FIELD REPAIR PROGRAM

One of the facility's problems was due to well field irregularities. The original six wells drilled in 1976 used PVC for the well casing but used cast iron turbine pumps and drop pipe. This was not a problem right away but over the years the deterioration that occurs provides for a potential source of fouling. In addition, the wells drilled for the expansion in 1979 also had problems. Although they had stainless pumps and drop pipe, they set the casings in clay formations instead of the limestone. Because the formation was unconsolidated, it allowed clay to be pumped into the system. Even though the five micron cartridge filters, which is part of the pretreatment, would stop most of it, some could still get through. We went through and replaced all the original pumps with stainless submersible and drop pipe, plus put liners in the newer wells, blocking off the clay layers.

This program showed immediate results. We used to change filters every 3 to 4 weeks. Now we change them every 4 months even though the monitoring parameters may not indictate that a change is required. There are 400 filters per change with a cost of approximately $4.00 per filter. As shown in Figure 10, this adds up to a substantial savings.

MEMBRANE PERFORMANCE

By going on an emergency basis for the membrane replacement, it did not allow time to complete the projects or repair the problems. We did, however, change our scale inhibitor from hex to AF100 immediately. The cost of the product was higher but the quality was also substantially better (or so we thought).

As the retrofit was winding down, the problems we experienced before were being noticed again. At the completion of the meter replacement program and the well field repairs, deterioration was still occurring. We attempted to clean the membranes but it did no good. The only questionable item left was the AF100; therefore, we switched to FLOCON 100.

DOW PLANT
JUNE 1987

DAY	RO PRD	RO BLND	PRD+ BLND	TRAN PUMP	PRD+ BLND -TRAN DIFF	REJ TOTL	PRD+ REJ+ BLND	RO RAW	PRD+ REJ+ BLND -RAW DIFF	EFFL PUMP
1	3591	782	4373	4690	-317	1182	5555	5670	-115	6876
2	4127	899	5026	5363	-337	1350	6376	6575	-199	5694
3	3959	843	4802	5135	-333	1301	6103	6226	-123	6047
4	2512	521	3033	3267	-234	810	3843	3916	-73	4706
5	3024	708	3732	4009	-277	979	4711	4772	-61	5378
6	3513	743	4256	4562	-306	1149	5405	5570	-165	5746
7	2958	618	3576	3854	-278	965	4541	4639	-98	5983
8	2964	636	3600	3878	-278	968	4568	4651	-83	5957
9	3892	880	4772	5134	-362	1276	6048	6213	-165	5703
10	2865	637	3502	3762	-260	928	4430	4568	-138	4287
11	1930	426	2356	2536	-180	637	2993	3026	-33	3777
12	1449	290	1739	1906	-167	476	2215	2239	-24	3874
13	2048	391	2439	2642	-203	666	3105	3137	-32	4557
14	1491	306	1797	1072	725	487	2284	2214	70	3566
15	1837	379	2216	2364	-148	604	2820	2737	83	4092
16	2420	516	2936	3142	-206	780	3716	3801	-85	5285
17	1937	430	2367	2517	-150	619	2986	2989	-3	6628
18	2589	608	3197	3424	-227	846	4043	4098	-55	7126
19	2593	579	3172	3326	-154	843	4015	4013	2	6428
20	2071	490	2561	2658	-97	674	3235	3169	66	6610
21	1584	378	1962	2066	-104	512	2474	2442	32	6687
22	2037	454	2491	2615	-124	660	3151	3102	49	6100
23	3180	715	3895	4225	-330	1065	4960	5103	-143	5477
24	3464	733	4197	4485	-288	1139	5336	5427	-91	5421
25	3445	742	4187	4461	-274	1122	5309	5459	-150	5840
26	2690	594	3284	3486	-202	884	4168	4236	-68	4742
27	2142	480	2622	2818	-196	713	3335	3415	-80	4072
28	1353	318	1671	1759	-88	447	2118	2064	54	4780
29	1071	260	1331	1403	-72	345	1676	1698	-22	4607
30	2112	511	2623	2768	-145	679	3302	3297	5	4261
31										
MIN	1071	260	1331	1072		345	1676	1698		3566
MAX	4127	899	5026	5363		1350	6376	6575		7126
AVG	2562	562	3124	3311	PERCENT BLEND	837	3961	4016		5344
TOT	76848	16867	93715	99327	18.00	25106	118821	120466		160307

FIGURE 8 Daily Flow Meter Data Sheet

APR 87 METER COMPARISON SHEET

*********************** RAW WATER COMPARISON *********************

WELL	DOW PLANT CALC	METERED	MET/CAL
1	13802	14302	103.6%
2	15279	15684	102.7%
3	25008	24359	97.4%
4	23136	23541	101.8%
5	0	0	ERR
6	5551	4776	86.0%
7	17299	17388	100.5%
8	16500	17345	105.1%
9	12638	13420	106.2%
10	21456	21377	99.6%
TOTAL	150669	152192	
TOTAL PLANT >>>>			140073

WELL	HYDRANAUTICS PLANT CALC	METERED	MET/CAL
11	8991	9053	100.7%
12	14256	15203	106.6%
13	14235	14497	101.8%
14	15341	15611	101.8%
15	12179	12557	103.1%
16	84	71	84.5%
17	15077	15532	103.0%
18	17919	17632	98.4%
19	9263	10032	108.3%
20	0	0	ERR
21	12558	13785	109.8%
22	10374	10861	104.7%
TOTAL	130275	134834	
TOTAL PLANT >>>>			130522

	DOW	HYDRANAUTICS
PLANT/CALC	92.97%	100.19%
PLANT/METER	92.04%	96.80%

NOTE: CALULATED=WELL HRS X GPM & METERS=INDIV WELL METERS(1st TO 1st)
TOTAL PLANT=COMBINED METER AT PLANT

***********************DOW SKID METER COMPARISON *********************

PROD	CALC	METER	MET/CAL	REJ	CALC	METER	MET/CAL
A	7396	7482	101.2%	A	2466	2449	99.3%
B	8015	7973	99.5%	B	2683	2677	99.8%
C	7787	7937	101.9%	C	2584	2692	104.2%
D	11215	11142	99.4%	D	3744	3696	98.7%
E	9792	9798	100.1%	E	3263	3161	96.9%
F	11397	11415	100.2%	F	3802	3738	98.3%
G	6999	6885	98.4%	G	2338	2315	99.0%
H	6283	6261	99.7%	H	2097	2132	101.6%
I	9966	9994	100.3%	I	3295	3025	91.8%
J	9201	9362	101.7%	J	3058	2996	98.0%

NOTE:CALC=HOURS X GPM & METER=PRODUCT AND/OR REJECT TOTALIZERS

*********************SYSTEM RECOVERY COMPARISON *********************

DOW	4-12	METER	MET/4-12	HYDRA	DESIGN	METER	MET/DES
A	74.99	75.34	100.5%	A	85.00	85.00	100.0%
B	74.92	74.86	99.9%	B	85.00	85.00	100.0%
C	75.08	74.67	99.5%	C	85.00	84.99	100.0%
D	74.97	75.09	100.2%	D	85.00	84.99	100.0%
E	75.01	75.61	100.8%	E	85.00	84.99	100.0%
F	74.98	75.33	100.5%	F	85.00	84.99	100.0%
G	74.96	74.84	99.8%	G	85.00	84.98	100.0%
H	74.97	74.60	99.5%	H	85.00	84.99	100.0%
I	75.15	76.76	102.1%			84.98	100.0%
J	75.06	75.76	100.9%				

NOTE: METER=RECOVERY CALC BY TOTALIZERS

****************COMBINED METERS vs INDIVID METERS *******************

CALC D PROD + D BLND = 110993 <> 115163 = METERED DOW TRANSFER
D PRD+ D REJ+ D BLND = 140324 <> 140073 = METERED DOW RAW

CALC H PROD + H BLND = 111587 <> 110535 = METERED HYDRA TRANSFER
H PRD+ H REJ+ H BLND = 130522 <> 134834 = HYDRA RAW(METERED WELLS)

FIGURE 9 Monthly Flow Meter Comparison Sheet

CARTRIDGE COST PER FILTER 1987	$4.44
NUMBER OF FILTERS USED PER CHANGE	400
TOTAL COST PER CHANGE	$1,776
NUMBER OF CHANGES FOR 1984	13
TOTAL COST FOR 1984	$23,088
NUMBER OF CHANGES FOR 1986	4
TOTAL COST FOR 1986	$7,104
TOTAL AMOUNT SAVED FOR YEAR 1986	$15,984

FIGURE 10 Cartridge Filter Cost Savings

Looking at the flows for the combined operations (all skids averaged together), on Figure 11 you notice where the meter replacement program was completed. Then the decline continues. In May 1985, the switch to FLOCON took place and you can see the system responding. Flows have now probably come back as much as they are going to (300 gpm), yet as we will see, delta p's (change in pressure) are still declining.

Figure 12 is a graph of the first stage delta p's (differential pressures). The dramatic increase in pressure indicate problems still occurring. Then, with the completion of meter recalibration and the cleaning program working, the pressures start to decline. With the delta p's still on the decline, it appears that what we have gained back will hold for some time. The second stage delta p's, graphed in Figure 13, were increasing but not as rapidly yet when programs were completed and cleaning took place, the increase stopped. Now both readings are running consistent and almost the same, 50 psi. This is not as good as if nothing happened but shows cleaning can work and systems can be brought back.

Not all is good news. As shown in Figure 14, the salt passage did rise more than expected; still well within acceptable limits so quality was not completely sacrificed. We can only attribute this to our continuing cleaning program. We now consider cleaning part of our maintenance program and feel every plant should do the same. Not only chemical cleaning but product flushes also.

Product flushes consist of taking product water and circulating it through the membranes using the cleaning system. Water being the best solvent, it aids in keeping the membranes as clean as possible. This has to help prolong their life.

PLANT EXPANSION

With the Dow plant beginning to operate consistently and efficiently, we could focus on the other projects going on. A building boom was taking place in the City and we knew it would not be long before we had to provide more potable water. The problems

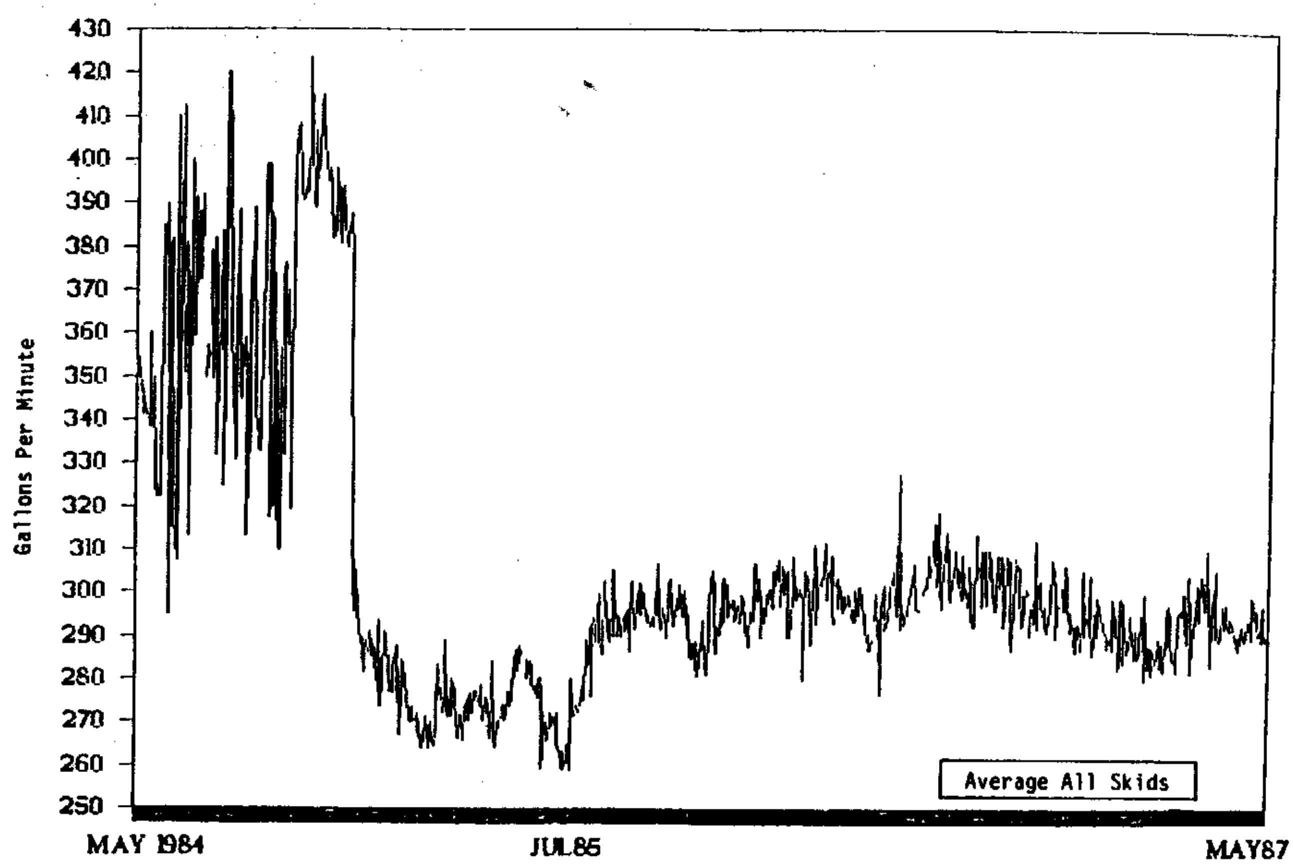

FIGURE 11 Average System Flows

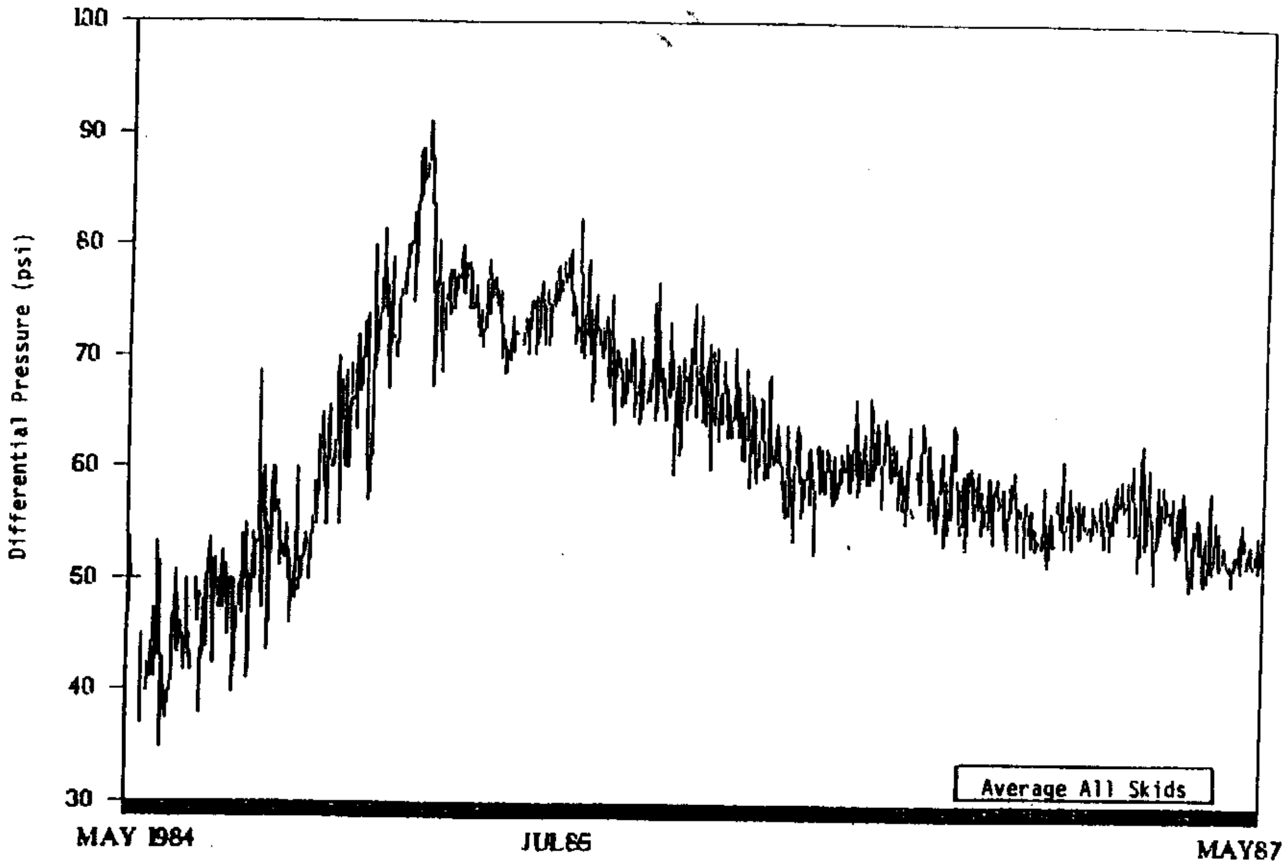

FIGURE 12 First Stage Delta P's

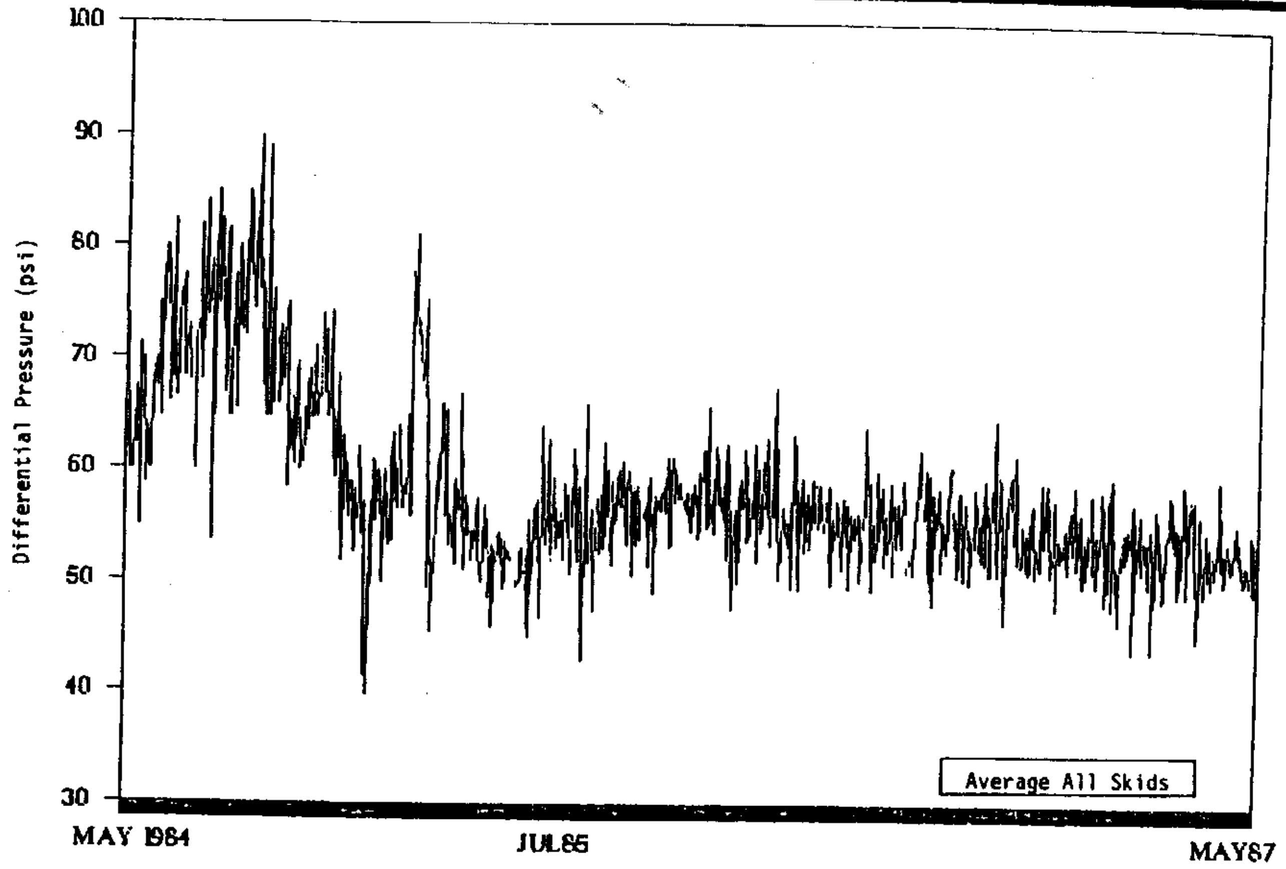

FIGURE 13 Second Stage Delta P's

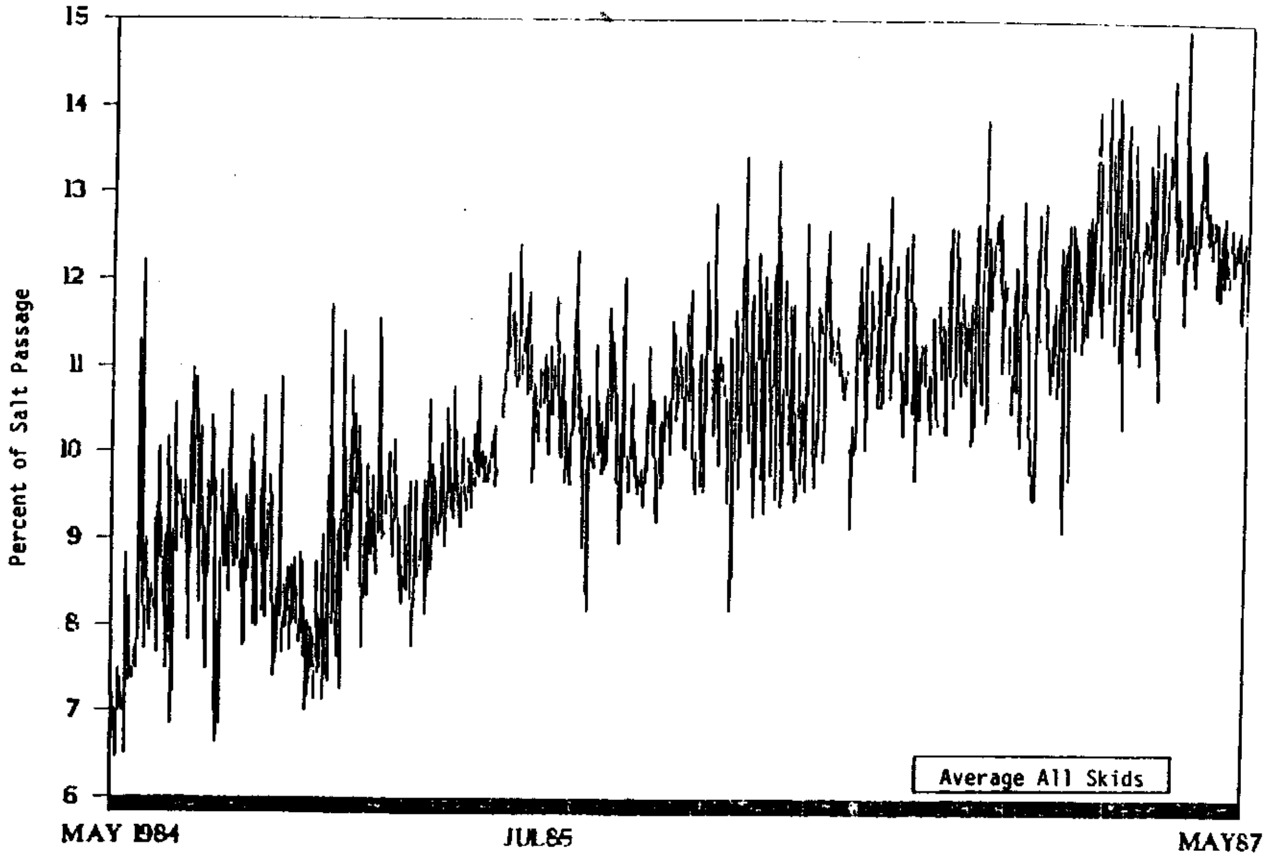

FIGURE 14 Salt Passage

encountered in the old plant encouraged the City officials to take action immediately. Therefore, in May 1984, we contracted Howard, Needles, Tannem and Bergendoff (HNTB) to construct a 7 mgd RO plant to be done on a fast-track program. HNTB immediately hired Mr. Ian Watson of Rostek, to draw up specs, evaluate the bids, and monitor the construction project.

In July, 1984, the contract was awarded to Hydranautics Water Systems. They installed a spiral wound system that operates at a 250 psi feed pressure with 85 percent recovery. The total production is 9 mgd including blend. Although not 100 percent complete, we were producing and using water from the system by May, 1985.

The short construction time was quite a feat since there were separate contracts for the other projects required. The contracts were for 12 supply and 6 monitor wells, raw water piping (6 miles), a 5 million gallon storage tank, the RO system, brine disposal line, and site restoration. The cost of the project was 8 million dollars. As can be seen in Table 1, the capital costs for the RO system was very reasonable. Not only are the capital costs reasonable but the operating costs are becoming as low, if not lower, than conventional treatment processes.

Table 1
CONTRACT COSTS FOR EXPANSION OF RO FACILITY
CITY OF CAPE CORAL, FLORIDA

Raw Water Supply		
12 Production Wells	$965,632	
6 Observation Wells	57,000	
Total		$1,022,632
Raw Water Mains		1,063,867
Site Preparation and Restoration		79,681
RO System		4,606,100
Brine Discharge Line		258,650
5 Million Gallon Storage Tank		811,469
TOTAL PROJECT COST		$7,842,399

OPERATING COSTS

We consider the operating costs as chemicals, labor, and electricity per 1,000 gallons of final product pumped. Until 1984, the City operated both a lime softening and a RO plant; therefore, direct comparisons can be made.

Table 2 shows costs of both operations for 1978 and 1984 and the increases of both. Even though the increases were in different categories, essentially the increases for both processes were the same. These costs represent two separate operations. They must be added together to represent the division costs shown at the bottom.

Table 2

OPERATING COSTS, WATER DIVISION, CITY OF CAPE CORAL
LIME SOFTENING, REVERSE OSMOSIS, AND TOTAL DIVISION

Lime Softening

	1978 Costs	1984 Costs	Increase
Chemicals	$0.06	$0.08	33%
Labor	$0.15	$0.33	120%
Electricity	$0.06	$0.16	167%
Total	$0.27	$0.57	111%

Reverse Osmosis

	1978 Costs	1984 Costs	Increase
Chemicals	$0.06	$0.13	116%
Labor	$0.11	$0.17	55%
Electricity	$0.22	$0.51	132%
Total	$0.39	$0.81	107%

Total Division Costs

	1978 Costs	1984 Costs	Increase
Chemicals	$0.12	$0.21	75%
Labor	$0.26	$0.50	92%
Electricity	$0.28	$0.67	139%
Total	$0.66	$1.38	109%

As both construction projects were nearing completion, the costs started to decline. When we were finally able to shut the lime plant off, the numbers began to reflect what it costs to run a large RO facility. Table 3 shows the RO costs and the division costs in 1984. Table 4 shows the current costs. You can see the dramatic decline.

Table 3
OPERATING COSTS FOR WATER DIVISION, CITY OF CAPE CORAL
1984 REVERSE OSMOSIS AND TOTAL DIVISION COSTS

	1984 RO Costs	1984 Division Costs
Chemicals	$0.13	$0.21
Labor	$0.17	$0.50
Electricity	$0.51	$0.67
Total	$0.81	$1.38

Table 4
OPERATING COSTS FOR WATER DIVISION, CITY OF CAPE CORAL
(1987 Costs are for Reverse Osmosis Only)

	1984 Division Costs	1987 Division Costs	Decrease
Electricity	$0.21	$0.09	57%
Labor	$0.50	$0.12	76%
Electricity	$0.67	$0.40	40%
Total	$1.38	$0.61	56%

The largest decline was in labor costs. By shutting down the lime plant we were actually able to reduce the staff from 18 people to the present 15. That accounts for 10 operators, 3 maintenance men, and 2 supervisors. The plant is operated 24 hours per day, 7 days per week. The costs include overtime.

The unit cost for electricity has risen over 200 percent since 1978. Yet with RO technology moving towards lower pressure membranes, these increases can be overcome. One good example is our reduction in energy usage. The savings we realized by switching from 400 to 250 psi was over 30 percent. With electric bills now of $80,000.00 a month, this adds up to a substantial savings.

On the average, we are only using approximately 50 percent of our installed capacity throughout the year. Therefore, labor and other costs will continue to decline as the production increases. The increases will not call for any additional personnel to handle the extra load.

The reduction in chemical costs is quite surprising; being that when we switched from hex to FLOCON 100, our costs for antiscalent increased by 200 percent. This was accomplished by proper monitoring of dosages and with the new plant a higher feed pH, thereby not using as much acid. This could only be done due to the FLOCON 100. Also, by using just the RO plant to provide all the water, we were able to reduce the chlorine residual from 3 ppm to .7 ppm. This reduced the chlorine costs by 30 percent. With the higher feed pH and not adding as much chlorine, the final pH did not have to be raised as high thus saving caustic. All those added together are the reasons for the chemical cost reduction.

If you look at the total operating costs for 1986, this total is actually less than the costs for 1978. One key point to remember is that we are only operating at 50 percent of installed capacity, so as production increases, costs will decrease. Of course, the bottom line for costs is what the consumers have to pay. In Cape Coral, that amounts to $1.65 per 1,000 gallons. A side note to that is we have not had a rate increase since 1981 even though we increased our production capacity by almost 50 percent.

Do those costs cover expenses? Yes, if you add the operating costs, membrane replacement, maintenance, and capital payback, it comes to approximately $1.40 per 1,000 gallons (give or take a penny or two). Even though costs are still foremost in all community minds, the major thrust from the regulatory agencies and the public is quality!

TRIHALOMETHANES (THM)

To give you a brief example of RO's effectiveness in controlling THM's, we can see in Table 5 the current THM readings. Before when we were operating just an RO plant, the readings were 90 to 120 parts per billion (ppb). Now, operating with only RO, those readings are 25 ppb. That includes approximately 20 percent blend water.

Table 5

TRIHALOMETHANE ANALYSIS RESULTS, CITY OF CAPE CORAL
(All Readings are in Parts Per Billion)
(Average of Quarterly Samples)

	1984	1987 (With Blend)
Chloroform	10.2	< 1.0*
Bromoform	46.1	22.9
Dibromochloromethane	21.6	3.6
Bromodichloromethane	10.3	< 1.0*
Total Trihalomethanes	88.2	26.5

*Below detection limit.

SUMMARY

You can see the versatility of an RO system. You can produce a quality of water that can meet the regulations even though they may change. Not many systems can do this. RO may not be perfect for every situation but the technology is advancing so fast, similar to the computer industry, that all future water supply projects will have to consider RO as a possibility.

The regulatory agencies, engineers, consultants, and field-related organizations must recognize RO as a cost-effective and operationally efficient treatment process as the City of Cape Coral has and is demonstrating. Once they recognize it, they can then recommend it as a viable alternative to conventional water treatment. When this trend starts and spreads, the questions, fears, worries and concerns over the process will be answered.

QUESTIONS AND ANSWERS

Mark R. Ashton

AUDIENCE

Does the $1.30 to $1.40/kgal cover the distribution cost?

MARK ASHTON

No, it only covers the production division. We do pump it out into the system. It does not cover the construction maintenance division who repair the lines, etc.

AUDIENCE

You sell the water for $1.65 so that must pay for the distribution?

MARK ASHTON

Yes, the $1.30 to $1.40 just covers the cost of operation and maintenance and the cost of paying back the capital.

AUDIENCE

I understood you to say your operating problems with the seven year old membranes resulted due to problems with the sodium hexametaphosphate and metering. Now were those problems there all along?

MARK ASHTON

The sodium hexametaphosphate problem was probably one which was created in the procurement process. The City operates on a bid type system. The low bidder sold us what we call "brown bag hex." Most bulk chemicals are sold in bags with all the markings on the bag about the standards that the chemicals meet. This hex came in a brown paper bag. It had no markings on it at all. They said it was hex and that

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was what we used. We thought the problem was a poor quality hex from the manufacturer. Before that, we did not experience that major a problem with the hex.

The metering problems, yes. They could have been going on for quite some time.

AUDIENCE

Does your permit call for a brine treatment?

MARK ASHTON

Yes, it does, now we don't have much brine treatment at our plant. In the new plant, all we have to do is add oxygen to the water and remove the hydrogen sulfide. We do that by simply adding chlorine to it until we reach the break point. We cannot have a chlorine residual, yet we remove all the hydrogen sulfide and that allows the dissolved oxygen to be put into the water. It is a very simple system and it is working rather well right now.

AUDIENCE

Have you noticed any change in the water quality data from the Lower Hawthorn aquifer since 1970?

MARK ASHTON

No, it has been so consistent we have to force ourselves to look at it every month to make sure it is doing right. The old wells which were previously free flowing, now have a static level, maybe 6-inches below the casings and they have been pumped continually since 1976.

AUDIENCE

About your THM data. Is that the average of your system-wide samples that you presented?

MARK ASHTON

Yes. Four samples throughout our distribution system.

AUDIENCE

Then you have a free residual?

MARK ASHTON

Yes.

AUDIENCE

Have you done any formation potential data?

MARK ASHTON

On our raw water? No, I have not. But if you noticed, I said we were blending about 20 percent in the RO plant at the present time and that is the same water that is going into the permeators. The 20 percent raised it from 2 to 23 ppb so you can see the potential is definitely there.

APPLICATIONS AND OPERATIONS

A ROUND TABLE DISCUSSION

Moderated by

Ian Watson
Rostek Services
Ft. Myers, Florida

With Panelists

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South Florida Water Management District
West Palm Beach, Florida

Bill Stimmel
South Florida Water Management District
West Palm Beach, Florida

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William Conlon
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DESALINATION IN SOUTH FLORIDA
August 21, 1987

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South Florida Water Management District
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IAN WATSON

Pete Rhoads has already spoken to you. Stan Winn is probably not going to say anything but he wants you to ask him some very pertinent questions about what the Water Management District does and how they feel about desalting, wastewater reuse, and pumping water out of the ground, and all that sort of stuff. Bill Harlow, who is the president of NWSIA spoke to you this morning. He is going to say a few words about the problems concerning the use of formaldehyde for sterilizing reverse osmosis systems. Bill Stimmel is in intergovernmental relations, liaison or something like that, and I have no idea what he is going to say. Bill Hendershaw is always unpredictable. Bill Conlon, I have known for a number of years and I am sure that he will be interesting. Then we will get together and I want the audience to ask questions. I have heard some complaints from people saying, "Gee, you should have had me on the program, I would have told them something." Well, here is your chance. If you want to say something, stand up and say it. It does not have to be a question. If we do not like it, we will tell you about it.

PETER RHOADS

The Water Management District underwrote the cost of this seminar. One of our major issues is how can we best serve local governments and the consulting community in disseminating information. You do not need to say anything right now but if you will stick that thought in the back of your mind. Either drop me a note or catch me sometime and give me your thoughts on the effectiveness of this seminar and how we might do our thing better in the future. I think that would help us out a lot. Now, I will pass the mike over to Mr. Winn.

STANLEY WINN

I really came to respond to any questions that you may have with respect to both the historical and contemporary direction that the South Florida Water Management District might conceive of taking with respect to desalination. I suggest that all of you in the desalination industry might start paying a little more attention to Florida in your travels and sales activities with respect to trying to sell different types of desalination. We appear to we get the short shrift of information and technology transfer that you can offer in terms of implementing these kinds of systems. To make a long story short, we just do not get the information in our local governments and consulting community on desalination that you, as manufacturers or agents in this area, are capable of providing. We need more information and I would just like to encourage you to spend more time in Florida trying to apply your solutions to a large number of water resource problems.

BILL HARLOW

I am up here because Ian heard about the troubles that Englewood had back in May. Let me explain to you a bit about Englewood. We are first in a lot of things. We were a sleepy little community in the 1920's and we took the step of incorporating ourselves in 1929--a big step. The community remained a small fishing community until the northern residents found the place and it started to grow.

The water district, of which I am the manager of, now consists of about 44 sections of land, 32 of which are in Sarasota County, with the remainder in Charlotte County. There has been an annual growth of about 10 percent since 1977. The Englewood Water District is a public body and is controlled by 9 elected supervisors. In 1977, they decided they did not want to do it themselves anymore so they hired an administrator, which is myself, Bill Harlow. Right after I came to work we had our first first. We were the first place in the State of Florida that suffered saltwater intrusion so we had to reduce pumpage on our well field. As a result of that, we found that our source of water was not going to last very long. At the same time, we decided to put in a reverse osmosis plant. Our reverse osmosis plant was designed with the idea that the building would contain 3 mgd of production capacity and we would use 1/2 mgd skids to fill up the building. We put the first 1/2 mgd skid in operation in December of 1982 and everything operated fine.

However, about a year and a half later, we suddenly discovered that the membranes, which were cellulose acetate, had started to deteriorate rather rapidly. Again, another first for the State. After negotiating with the membrane manufacturer, Hydranautics, we replaced them with thin film composite (TFC) membranes and went on our merry way again.

This past year because of the increased need for water, we installed two more 1/2 mgd trains. However, the TFC membranes began to show indications that they were not performing properly. To correct this, we then started to do what we call a series of high pH flushes. Every time that the production would suffer we would flush the membranes with a solution of permeate which had been adjusted to a pH of 10.5. This brought the system back every time but it would be needed again on a more shortened period of time. Finally, Hydranautics came to us and said they thought that we needed to try to sterilize (disinfect) the membranes. So as a result of that, we did a standard cleaning job on the membranes first and followed it with a formaldehyde treatment. It is the formaldehyde treatment that got us into trouble.

The formaldehyde treatment was a typical flush situation in which we had mixed up about 700 gallons of a 1 percent formaldehyde solution which contained about 50 pounds of 100 percent formaldehyde. Our operators started the flush and as the flush was proceeding they noticed that the 700 gallons, instead of remaining at 700 gallons, as it was circulating began disappearing. They immediately thought through the thing and discovered that it was going out into our plant's clear well. As soon as they realized that, they checked it by the smell. Then they shut off the clear well transfer pump which, incidently, was not running at the time. They also had enough smarts to isolate the 2 million gallon storage tank that the clear well pumped to. The net result was that we never put any formaldehyde in the community's distribution system. They called in the plant superintendent, confirmed that they had formaldehyde in the clear well and proceeded to make arrangements to dump the contents of the clear well on the ground around the clear well. They also started to dump the water in the 2 million gallon tank.

The next morning I got on the telephone and I called the County Health Department. When they did not respond back because they were busy, I then called the Tampa office of the DER and fessed up to the fact that we had spilled some formaldehyde on the ground, that we had some formaldehyde in one of our storage tanks and what was I to do next. There was a big gasp at the end of the telephone, "We will have to talk to Tallahassee," they said. So we cooled our heels for a little while. Pretty soon the Tampa office called me and said "We want you to flush out that tank 3 times and then take some samples and we will tell you what to do next." So we flushed the tank out overnight and fortunately we had had an engineer from CH2M HILL, the engineering firm that gives us consulting advice, at the plant during the time that this happened. That result was that we had taken a fairly good round of samples. We have a plant laboratory that is capable of analyzing for formaldehyde except that our laboratory chemist had gone off on a 3 week vacation. His assistant knew absolutely nothing about running a chromotograph.

So we had to locate someplace in the State of Florida that could analyze for formaldehyde in water. We discovered that there is no place in the State of Florida that is set up to test for formaldehyde in water on a regular basis. And anybody who would be able to do this, it would take them at least 3 to 5 days. We located a laboratory out in California that could do it provided we could get them out there. So we flew our samples out to California and we paid them $800.00 per sample to give us a 24 hour turnaround. The results came back indicating that we were down to about 530 micrograms per liter on the third sample of the flush and about 380 micrograms per liter on the final sample.

We reported this back to Tampa. Tampa said, "No, that is not good enough to put the water back into the mains, you have to get it down below the detectable limits of the analysis." The detectable limits of the analysis, as reported back to us by the laboratory, was about 50 ppb. So there we sat, we had about a million and a half gallons of water in a tank, we did not know what to do with it. We asked Tampa, "What can we do with this?" "Oh, you cannot dump any more of that formaldehyde on the ground." "Well, what am I suppose to do with it?" "Well, maybe you ought to put it down your disposal well." We have a disposal well which is receiving the reject stream from the RO plant now. "Okay, we will do that." So, we went out and made arrangements to get the necessary piping connected from the 2 million gallon tank through a pump to the wellhead and got ready to do that.

About the time that we were ready to do this, I got a frantic telephone call from the gentleman in the Tampa DER office in charge of disposal wells. He said, "Mr. Harlow, you cannot put that water down the disposal well. You are not permitted to put formaldehyde underground." About this point, I was ready to call Governor Martinez, but after a long period of time, on Friday afternoon, around 5:45, I finally got permission to pump that water underground. So we pumped the water underground over the weekend and Monday morning we took another series of samples. In the meantime, I was getting chastisement for the fact that we had sent our samples out to California, why hadn't we used the DER laboratory in Jacksonville? Well, it turned out that Jacksonville can analyze for formaldehyde in air but they cannot analyze for formaldehyde in water so we came out pretty well in our choice of laboratory. It ended up that it took us two weeks to get our formaldehyde escapade behind us.

Now, the point of what I am trying to say to you, is that there are some things you need to know about this experience that we had at Englewood that pertain to the rest of the industry, that is using RO processing now. At the time that I could not analyze for formaldehyde in water, I started making telephone calls around to the various plants in the Englewood area. I won't name the plants because I do not want to get them in trouble. One of the plants said we do not have any way of analyzing for formaldehyde when we do these things. What we do is that we take the water that is coming off the permeate stream and dump it on the ground. When we cannot smell the formaldehyde anymore, we turn it back into the mains. Another one said, "Well, we test it regularly with a Hach kit." When my chemist came back from vacation he said, "Yeah, but I do not think the Hach kit will tell you anything because it has got hydrogen sulfide mixed in with it and the Hach kit is sensitive to the hydrogen sulfide."

Another item I would like to mention to you concerns the way that membranes are shipped in from the manufacturer. Every membrane that comes in is in a nice plastic bag and guess what is in the plastic bag? Formaldehyde. So there we are friends, we have got ourselves a little problem. It so happens that we did a lot of research work. It is not the kind of research that we are proud of and I am not going to publish a paper on it but we did look at the California water quality data. We discovered that 1,800 ppm of formaldehyde would have been acceptable in the main without causing any health troubles to any of our residents of the District. The samples we took indicated that nothing ever went into the mains. There is no real published EPA guidelines as to what to do with this material and yet we are using it.

So there you are, this is one of the problems that faces the RO industry today. It is one that we all ought to recognize. It is one that we all ought to think about. We also did some thinking about this because of what happened. We looked into some of the chemicals that we are using to wash the membranes. Of the 15 to 20 chemicals that are sometimes used in the washing of the membranes, only three of them are not on the list of hazardous substances that was published in the Federal Register on July 28th. So think about that one too.

We took some steps in Englewood to prevent this from happening again. One of the things that we did is to install a double block and a bleed on the permeate connection to our main header. This way, anytime one of our trains is being treated, we have got the double block and bleed, just like it would be handled in a hazardous chemical plant. The material would be isolated and cannot get into our distribution mains. Well, that is the story of our escapades in Englewood. I hope no one else ever has that sort of problem.

BILL STIMMEL

I work for the South Florida Water Management District in a program called governmental assistance. It is designed primarily to strengthen the stewardship relationships between regional and local governments and the management of our water resources. I am not going to pretend to be an expert like all of you are in the water resource technology business. As a boundary spanner in getting out there and working in the arena with local governments, I can tell you that the future looks very good for this new technology that I have heard about today.

Starting in 1984, with the adoption of the State Comprehensive Plan, there were policies and objectives included in that document that stressed the need to move forward with this new technology, particularly, reverse osmosis. Furthermore, in 1985, the State Water Use Plan was adopted and it also elaborated on the need to move forward in developing this new technology. There are 11 regional planning councils in the state, not all of which have as active a coastal area that they are responsible for, but the ones that do have also identified reverse osmosis and other types of desalination techniques as something that looks promising.

So, in the general state, regional, and local government planning perspective, I would tell you that the door is wide open for you as an industry to move your products and your technology forward. That to me is a very positive indicator of the local governments dealing with the growth management related type issues that we have now and doing it in a more pro-active mode than perhaps we have done in the past. I will also tell you that the South Florida Water Management District has taken the lead and may become an interested partner with you, more in the actual construction, development, and transmission of water. This is a result of what happened in this session of the legislature, born out of a matter between Brevard County and Osceola County.

The Senate and House leadership asked the South Florida Water Management District to take the lead in trying to deal with a major water supply problem. It is the old coastal versus inland county issue that you may have heard of in the past, particularly on the west coast. The South Florida Water Management District is moving in that direction now and I am excited about the fact that, number one, we have taken the lead, and number two, there are a lot of people that are now going to be watching us, particularly in the legislative area, to see how well we perform. I think our water management district has the capability of advancing into this new area and we certainly have a staff of very competent professionals and technical people to move that program forward.

So in summary, I would just say that in general, the attitude and interest out there, particularly with the elected official groups, is very positive. I think you will see on the state, region, and local government levels a very strong interest in desalination technology.

BILL HENDERSHAW

I am Bill Hendershaw of Hydropro. Ian gave me 5 minutes to talk about the key aspects of operation and preventative maintenance. I will be brief about the operational side. Basic to the correct operation of a reverse osmosis unit is that you must maintain proper chemical dosing levels. It is surprising, particularly in the smaller plants, how you can find that they have wandered all over the place in their dosing levels. In the larger, more sophisticated plants with their online instrumentation, they can obviously do a better job in tracking and maintaining proper chemical dosing levels and also run at the proper rate of flow and recovery. If there is a problem occurring with a plant, probably one of the first things to do is to lower the percent recovery and thus stress your membranes less.

On the maintenance side, data collection is very important. In days of old we tried very hard to make sure that an RO system did not appear to the operator as a black box. With good data collection, someone from the outside who reviewed the data or was responsible for suddenly sorting through a problem, had some chance of figuring out what happened in the past.

Among the data that should be collected are the daily logs and the weekly profile logs. In a plant that is running at steady-state conditions and everything is going well, it gets to be a real pain to keep logs current. The result is that logs come in with just a few conductivities and no flow measurements. All you have is some pressure and temperature readings and you are missing some other data. Then comes the day you have to put it all back together to find out what the problem is and you find you cannot even make a simple graph or correlate things together.

Simple maintenance chores like keeping up on oil changes, changing the chemicals in the tank when you are suppose to, and replacing micron filters can get delayed. It is very strange to walk into a plant and find they have not changed the cartridge filters in a year or two. You are suppose to do that. It is important to use the proper chemicals and micron filters. Do not use cheap substitutions that some salesman may ply on you as being an equal. If you use the time and money to research it, you will find you have been sold a bill of goods.

Instrument calibrations are critical. Nothing worse than getting flow data that is totally meaningless when you check it with a bucket and stop watch and find out that every flow instrument in the plant is completely out of whack. They should certainly be calibrated, if not on a monthly basis, certainly in some of the more sophisticated plants, on a half-yearly basis.

Electrical problems are probably the biggest headache for most operators. Some kind of preventative maintenance program, whether it is bimonthly or whatever, looking at amperages and inspecting the relays in the plant to see if they are at the stage where they are starting to be smoked out or suddenly stink. More sophisticated survey methods like infrared or sonic should be employed on some periodic basis. If you have got a plant that you have spent one or two million dollars in capital cost to put together, then it is certainly not too much to spend $500 per year on, say an infrared inspection.

BILL CONLON

Ian asked me to talk about the concentrate disposal problems that we have in the state. This is a very important area of the membrane process. Earlier, Dick Derowitsch alluded to the fact that different terminology is used in the industry. We do have a problem and I know some of you, as lay people who are trying to learn about RO, have heard us use flux for flow; raw water for feedwater; and product, permeate, or finish water for the product water. We use brine, reject, and concentrate for the waste product. For the waste product, I think it is about time we all adapted the word concentrate.

I looked up the word brine to see what it meant in the dictionary and it said water of the sea. In a technical dictionary it said seawater containing a higher concentration of dissolved salt than in the ordinary ocean. In a joint AWWA-WPCF publication dictionary, it says brine is concentrated brackish, saline, or seawater containing more than 36,000 mg/l of total dissolved solids which is more definite. I think we have a lot of processes such as nano-filtration, membrane softening, and low pressure RO that do not concentrate up to these levels. One word that covers it all would be concentrate which means a product of concentration. I think we all need to adapt that word right now and for those of you new in the business, let us start using that word because I think FDER and regulatory agencies in other states have a problem with the word brine. When they hear the word brine, they think of something terrible from a pickle factory. We get in a pickle using that word.

Another word we hear for the waste product is reject, which means something imperfect, an imperfect article. At times we actually try to use concentrate for irrigation and for mixing and blending with other waters. So we do not want to call it reject if we are going to do that.

When we started in 1985 to run into problems with disposing of concentrate, I started to look elsewhere, seeing the handwriting on the wall. Maybe we were going to get rid of the one process, or membrane processes, and hold hope with the more stricter regulations and more stricter MCL's coming out for the future. If we govern ourselves out of the business by governing where we can put the reject, that is the concentrate, there I go again, then we have a problem.

I found an AWWA committee report; there is a committee that actually looks at water treatment plant disposal of waste chemicals. They did a questionnaire, sending out 154 questionnaires, and like all questionnaires, only about 36 of these came back. They found that zeolite softening plants had a disposal problem or they thought they would have a disposal problem. Looking at the survey, 27 of the 36 replies were from zeolite plants and here is the way they get rid of some of their concentrates: sewage plant via sewers - 13; river or stream discharge - 8 (I doubt if we can get away with that!); groundwater recharge - 1; and ocean disposal - 3.

The report summary stated that only two plants had a disposal problem and both problems were solved. A 1-mgd industrial plant here in Florida had a zeolite plant and they finally mixed their wastewater with the brine from the ion exchange plant and put it in a percolation pond. In Maine there was a small plant that took its brine to the city dump. The dump closed so they stopped softening.

The final statement in the findings said that no state reported that disposal of brine was a real problem. I guess they did not talk to us here in Florida. There have been no reported problems in connection with "detection with the above mentioned disposal methods and it can be concluded that there are no current or anticipated problems of significance in the method of brine waste disposal in existing water treatment plants in the country."

Well, in Florida, the disposal of concentrate started in the 1960's with the Florida Keys Aqueduct Authority's distillation plant. Later in 1971, our company, Post Buckley, put in the first membrane plant in Florida which was one of my first assignments as a project engineer. We disposed of the concentrate to a seawater canal which then went to the ocean. But back then the old Department of Health, which later became the Department of Rehabilitative & Health Services which then split out to DPC and then became the DER as we know it today, said, "Well, we see some sulfur slime coming out of your outflow there. We want you to get rid of it, we think it may be toxic." I used to see the fish just congregating around the outflow waiting for the slime to slough off and then they would eat it. I never saw any fish die. We elevated the pH to 9, it turned orange and died, and the fish still ate it, and we did not hurt the environment.

So one of the things that came out of that, was that the regulators did not know where to, or how to, permit concentrate discharge in those days. They knew it was not domestic waste so they said we will put it in this catchall category called industrial waste. It was not domestic so it was industrial. So since then, we have had to live with ever stricter regulations which makes it difficult.

Many of you feel like I and others in DER, local agencies and state offices at high levels, that there ought to be a separate concentrate permit, a concentrate disposal permit. I hope that someday they all get around to talking together and do this.

So around in 1985, as I said, problems in Florida began to develop. Recently in Venice, for just a renewal of a permit, they were given numerous types of problems and there they have been discharging for years. Cape Coral with the expansion, which Mark Ashton would have alluded to, Lake Finister, when they went to that lake they had problems. In Englewood they were limited in flow so they eventually had to go to deep well injection.

Recently we did an evaluation of a new plant expansion as to whether or not this client should go to lime softening or to membrane softening. The evaluation turned out, this was a plant in Lee County, that they should go membrane softening. So we went to DER about the permitting.

First, here is what we were going to do. At present, they were taking their sewage effluent and putting it in a lined pond with makeup water from a well that had higher chlorides than our proposed concentrate. All we proposed to do was to take a lower concentration of water and replace that well, which I am sure the water management district would have liked to have seen out of service, and mix it with the sewage effluent and then put it on a golf course. DER said no, you cannot do that. Until now, disposal methods have been disposal to the ocean, bays or intracoastal waterways, or blending followed by spray irrigation.

In 1978 we put in a plant running at 200 psi in the Pelican Bay Improvement District in Naples. There we did something a little innovative. We had a lined pond and into it were put the sewage effluent, plus makeup water, and all the concentrate from the RO plant which has a concentration of about 5,000 mg/l. The three flows are mixed together and have been used for spray irrigation until 1987, when they tied into a regional system in the City of Naples. There have been no ill effects that we know of and they have been monitoring the wells there for years. I am sure the data go back and could be examined to see if there was any detrimental effect but we know of none.

In addition to that, there are brackish lakes or streams where the background water is worse than the concentrate we are disposing of. We have two plants in Sarasota County where we voluntarily went to deep well injection mainly because it was more economical. We could not find nearby brackish water where we could be within 10 percent of background with our concentrate. We analyzed the cost of going many miles to a brackish surface water versus deep well injection and we went the deep well injection route. At Acme Improvement District, we have a plant that we designed. They provided for the future and they went ahead and lined their sewage treatment injection well anticipating that they would have to go that way to get rid of their concentrate.

Out of the state, in Missouri, we did a 4-mgd plant and there they did not know what RO was. They thought of it as a black box system. We got them in touch with Glenn Dykes here in Florida and he told them what RO was and that we had over 50 mgd of installed capacity here in Florida. We were able to convince them, by mass balance, that we could discharge to the river where they had been discharging to the river for 98 years.

They had 1,400 TDS water coming into the plant and they were drinking this water. It would go through the sewer plant and back out to the river. They were doing this for 98 years or so. And so what we proposed to do was give them a 100 TDS water to drink, let that go through to the sewage plant and then we would mix the RO concentrate at the tail end and put it in the river and they bought it. And that is the kind of sound engineering judgement that we need when permitting. We all need to look at other methods, innovative methods, such as solar ponds, or maybe vapor compression, to get rid of brine (concentrate) in the future.

Right now, the South Florida Water Management District is funding a project in Boynton Beach, in which we are managing, a membrane softening pilot program. As part of the pilot program, there is an artificial spray field which the City spent $261,000 to create. It is 22,000 square feet, bermed all around, and equipped with monitoring wells. We are taking the concentrate from two membrane process plants and disposing of it by spray irrigation on the field. As an end result, I think the water management district is looking for a way of proving, through an innovative model, a way to dispose of concentrate. Dr. Toddy from FAU and Dr. Cooper from FIU are involved in this project. In addition to that, we are also using an EDR unit as a concentrator just to see how that would work on the brine from the RO units.

To date, since 1971 and the Ocean Reef Club, I know of no problem, fish kills or otherwise, that have ever developed from any of our brine disposal or concentrate disposal sites. If any of you know of any sites I would like to hear from you on that. Perhaps future studies, maybe by the South Florida Water Management District, or others, could look into all those existing sites and determine if there has been any problem, or if any problem could occur. Maybe this would help and assist us in assuring the DER that there are no problems with the concentrate.

Earlier this year when Ian called me, we started to discuss these problems and we thought it best if we could have a workshop with DER to discuss all the problems that we, as consultants and the cities, were having with renewing permits and get some kind of regulatory relief.

It just so happens that the new second in command, John Shearer at DER, was my old boss. He helped me to get a workshop set up and on June 26, 1987, we had a workshop meeting at our office in Tampa.

There were 25 attendees, 11 people from DER, 5 were heads of different sections of DER in Tallahassee, 6 others from other local DER offices; the others were, 12 consultants, 2 city representatives, and 1 lobbyist from the oil industry. Believe it or not, the oil industry also has a problem in the disposal of brine.

In summary, a greater awareness of the disposal problems by DER was had and they recognize there is a problem by DER with inconsistency in handling the permitting from one office to another. In fact, John Shearer made a comment during our meeting that he noticed there were some inconsistencies and maybe it would be nice to go to the office that would give the best deal. As a result of the meeting, tasks were assigned to five individuals, four from DER/Tallahassee and one professional, Tom Missimer. These assignments are designed to give some sort of regulatory relief in several areas.

I would like to read quickly from an excerpt from a letter that John Shearer wrote to me recently, dated July 20th. He said: "Thanks for organizing the workshop on concentrate disposal. I think the discussion was helpful to everyone and my notes indicate the Department committed to the following action. I will initiate discussion on issues related to EPA classification of the concentrate and injection well requirements with Region IV EPA Atlanta and Washington within six weeks. Howard Rhoads will initiate revisions to the GEOAVE rules within three months, that is the groundwater rules. Greg Wilkins, who is head of permitting, will make determination as to the consistent permitting practices covering concentrate disposal within two weeks." (He has already done that.) "Tom Missimer will summarize water management district concerns and practices and send them to me as soon as possible. Roxanne Dow, who heads up the Surface Water Discharge section, is assigned to summarize mixing zone procedures and send that to him as soon as possible. Howard Rhoads will collect the summarized information related to the minimum groundwater and surface water quality standards for free froms to send to him as soon as possible and when he has collected some of these documents and we have additional target dates, I will send follow-up information to all the attendees."

There are many people here that were at that meeting and they can talk to you later about some of the results we have got.

In summary, I think that we as membrane process users, consultants, and regulatory agencies need to work together to keep the issue in perspective. From a regulatory standpoint, they should enforce the regulations as they are written but use good engineering judgement where it is obvious problems will occur, or in the case of permit renewal, where it does not exist. We, as engineers, have the responsibility and obligation of protecting the environment and we have to look for new innovative ways to dispose of the concentrate. As I said, membrane processes may not be a panacea to all treatment problems but they may be one way, perhaps the best way, of meeting new MCL's and we do not want to regulate ourselves out of this business.

IAN WATSON

Before we go on, I want to relate to you a story about Cape Coral. When we were trying to get the permit to discharge the reject, or concentrate, from the new plant at Cape Coral, we had applied for mixing zones for radionuclides and fluorides and there was no problem. We were going to get the permit, they advertised, and at that time there was a very young aggressive TV reporter in Ft. Myers who was just fascinated by this technology and he was going to do a special, go to CBS in New York and everybody was going to come down to Cape Coral, take pictures of the plant, and interview everybody. Somebody said suddenly, "What about the wastewater?"

So he made an appointment, came over one day, and we thought that we have got to be careful. So, we took a sample of the feedwater going into the plant and the permeate coming out of the plant and the concentrate coming out of the plant. We set them on a desk in the lab and you could not tell the difference between them. No color, no suspended solids, no nothing.

That night on the news he picked up one of those flasks and said "This is the dirty wastewater that we are throwing into our lake in Cape Coral." He never came back and if he had, I think he would have been severely reprimanded.

So we have heard from the government side, we have heard about some of the operation and maintenance, and a specific sterilization problem. Bill Conlon has given some insight into concentrate. Since you cannot get 100 percent recovery, whatever you have got left over is concentrate and you have got to get rid of it in an environmentally acceptable fashion.

In the audience we have membrane manufacturer's representatives, we have systems manufacturing representatives, a number of consulting engineers with some experience, and a number of consulting engineers in the learning process. We have some users and government people. I am sure there must be a lot of comments and some questions; some points of view--perhaps controversial, perhaps not, that some of you would like to discuss for the next hour and I would like to use up all that time before I call on Dave Furukawa to wrap up the seminar.

AUDIENCE

A comment on Mr. Harlow's story of desperation. Wouldn't it be refreshing if we could get the same latitude in our use of chemicals that, for example, as the breweries get with beer? I understand that formaldehyde is a component of a number of bottled products. Yet we see this hysteria when formaldehyde is involved anywhere near a water treatment plant. I do not propose that anybody deliberately inject formaldehyde into the finished products even though it is being done in certain food and beverage products.

There is a NWSIA white paper out on trichloroethylene in drinking water versus trichloroethylene in instant coffee. Right now, technically in the State of Arizona, if you pour a cup of decaffinated coffee on the ground you are in violation of the State's Groundwater Protection Act. I would like to make a comment in favor of a little bit of more of reasonability in these regulations.

BILL HARLOW

I second what you are saying. There was a great deal of worry about putting 0.56 pounds of formaldehyde down a well after we had spilled over 30 pounds on the ground around that clear well. There was some consternation when we started taking samples around the Englewood Water District. It so happens that we have 54 potable wells that we use in our lime softening plant so we started taking samples there. We found formaldehyde levels of up around 100 ppb in the water coming out of those wells and it certainly did not come from the formaldehyde which we spilled on the ground in the clear well as in some cases the wells were as much as 5 miles from the site. There is a background level of formaldehyde in this world that we need to reckon on and set our sights accordingly.

BILL CONLON

In Sarasota County, we have been asked, on our design of RO plants, to include scavenger tanks on the new designs. We have scavenger tanks in several plants in which we put the residue of the chemicals from our cleaning. We do not clean everyday or you are not suppose to clean every day, but you may clean every six months or some period less than that. So what we do is trickle those wastes to the sewer plant. At the worse case, formaldehyde, if it were in there, would be a biocide. There is not enough there to kill the biomass in the sewer plant when you do it that way.

The other chemicals such as Biz, which is a soap, is typically used but there are some that Bill Harlow addressed that are on the EPA list. By the way, the problem with concentrates is that EPA says that the concentrate is corrosive because of pH.

BILL HENDERSHAW

I guess it is a simple design point. When I first came to Florida I never considered that cleaning a potable plant could be a cross connection problem. Stuart McClellan is here in the audience and I think he came up with a simple but novel approach that is probably implemented in over half the plants in the state. I am actually surprised it is not 100 percent.

It is a very simplistic atmospheric break during cleaning. You simply break every product header that you are cleaning and you connect your cleaning hose back to your tank. It is impossible for you to contaminant any piping in the product side downstream as long as you follow that. When you are done it is just like when the membrane was new. If it did have contamination by formaldehyde, we employed purification by dilution. You run for 24 hours and obviously from a volume turn over, a concentration after about six volumes is actually down quite low, so after 24 hours it is down significantly.

IAN WATSON

That is a good point about the break in the permeate line. I reviewed a number of designs lately done by other engineers who all seem to have a fascination with block valves and direct cleaning connections and it really is not the way to go. If you take a piece of the pipe out and hook up the cleaning hoses, you cannot possibly contaminant the product.

BILL HENDERSHAW

Just one comment on blocked valves in your RO plant. It is not a good practice to put a valve in your product water line because a new operator might shut it and if he does, there goes your membrane.

AUDIENCE

I would like to ask if anybody considered using chemical destruction of the formaldehyde. It might be possible to add a little hydrogen peroxide and you will have ended up with formic acid and no problem. In addition, there are membranes that come without formaldehyde.

IAN WATSON

That is a point. I think that most of the membrane manufacturers, if not all of them now, ship without formaldehyde.

AUDIENCE

I wanted to comment on what Bill Conlon was talking about--the solution. I think we have all heard that the cost of desalination by membrane technique will be increased due to the disposal issue and I think we are all trying to find the root of reality. How dangerous is that to the environment--the disposal of concentrate?

But there are already existing technical solutions. He alluded to one, vapor compression, on the tail end of the reject or the concentrate streams. There are big plants already built, not in this country, but plants in Saudi Arabia. One is a 10 mgd inland desalination plant that has 99 percent recovery of all water by desalination; 90 percent roughly in RO and 10 percent by distillation.

There is an example of that in California, in the famous Kesterson situation at Los Banos, where the Department of Water Resources in California installed a bottoming cycle on the RO using a technique we call seed slurry plus vapor compression which allows 98 percent recovery of all the water. And, even more interesting, but maybe not necessarily applicable in Florida, is use of the concentrate which is placed in solar ponds and used to generate energy to run some of the RO process.

We need to make better use of the advanced technology that exists, both membrane and distillation, in order to reduce potentially higher costs. There is some issue of the optimum point between the amount of pretreatment for RO and running the RO at a lower salt rejection and combining it with a distillation plant which takes advantage of blending the high quality distillate with the lower quality permeate from the RO giving a much better quality product.

The other example of solutions that exists is in the power industry which continually does that on cooling tower blowdown in inland locations which really goes to official zero discharge. Many of these plants are built by companies such as Resource Conservation Corporation (RCC) or Israel Desalination Engineers (IDE) which specialize in concentration of desalination brines. And, this is really a brine because when you concentrate the product from, for example the Los Banos pilot plant, it was 270,000 ppm. This is a heavy brine and really leaves only 2 or 3 percent of the original volume. That was the comment, now I have a question.

We are talking about, obviously in Florida, a lot of small desalination plants. There are RO, ED, and EDR plants in the local communities but I did not hear on the horizon, anybody talking about big desalination plants. It is no surprise that big plants exist in the world. There are 3 billion gallons of it around the world. In places like Saudi Arabia there are plants with 270,000 mgd in one place and soon will be 300,000.

The question is, should we, or Florida in general, consider a big desalting plant? Should they work together with Florida Power & Light or other power companies to look at large schemes and what are the possibilities? What is really Florida's option to demonstrate that large scale desalting technologies are viable? The unit price is smaller on larger plants than with many smaller RO plants. And a final comment is that Florida needs help from the Federal government. We, as NWSIA, are trying to lobby for demonstration technology. I am chairing the legislative committee of NWSIA and we are prepared to lobby for demonstration plants, not necessarily seawater or brackish water, but I would like to see interesting demonstrations of the technology and bring the demonstration to Florida with support from the Federal government.

IAN WATSON

I would like to address the question about the large plants. Bill looked at some big ones. I looked at some big ones, at least big by our standards; 20-, 30-, 40-mgd. Sarasota County is looking at the first increment of a 52 mgd plant.

You may remember some time ago, Bob Bailey tried to interest the City of Melbourne in a combined mass-burn resource-recovery and RO plant. The economics looked good but no one was interested as they were getting ready to pump water from Osceola County. The technology is there and there are people in the State of Florida who are capable of applying all kinds of technology to the problems of energy recovery which has been a big subject for many years. Reduction of concentrate volume and elimination of concentrate by going to a solid separator of salt product have been looked at in several places in the United States and overseas but not yet in Florida. However, the technology is there and we should be looking at it as the plants get bigger and bigger. I am sure they will and we should be looking at some of those solutions.

BILL CONLON

A comment on resource recovery, I think this is the kind of thing that is going to have to be because Florida's population is growing so rapidly. Every time you turn around you see new buildings, etc., but solid waste disposal sites are going to have to be someday, a thing of the past. This is because we have another problem and that is the groundwater pollution and with the high water tables in Florida and leachate plumes spreading and right now coming close to some of the well fields in Florida.

I have a client that has this kind of problem approaching their well field. The more they pump as they grow, they may be pulling this leachate in. Here is a good place to site, in the future, a resource recovery type plant where we can even take water from leachate plumes and use that as the feedwater to those distillation systems and get rid of that bad product. There may be a way if we site, in the future, RO plants or membrane plants near power plants where they may be able to use the concentrate.

We are looking at several projects in conjunction with resource recovery where we can get rid of wastewater effluent too in conjunction with distillation. Another thing is an innovative way that I heard from Professor Harry Gregor at Columbia University. He said that we should look at taking the concentrate from these different plants and with an ion exchange type electrodialysis membrane, splitting it off into acid and caustic streams so we could adjust the pH coming in and then adjust it going out. Sort of a perpetual motion type plant.

IAN WATSON

Bill, do you want to say something about some cooperation with the Federal government?

BILL STIMMEL

No, but I would like to comment on something you said. This matter between Osceola and Brevard County--over 100 different alternatives were looked at for a regional supply and it boiled down to three basic alternatives. One was the continuation of the use of Lake Washington which is the headwaters of the St. Johns River, part of the headwaters anyway, the second alternative was RO, and the third alternative, and the one that continued the litigation for 7 years, was the one going on to the neighboring Osceola County.

Now, the dilemma that we can often find ourselves in is the rather strong public policy that says we support the continuation of alternative water supply technology such as RO and yet it is fairly clear, to me anyway, and to the people that I work with, that we are now looking at major transportation of water from the inland areas to the coastal areas to continue to fuel the growth and development taking place in our coastal areas. You said that the RO alternative was laid out supposedly to the elected official body and was not picked up on. I do not really have a good strong, clear understanding of why that concept never flew but if you are looking at a large scale RO facility that is capable of being constructed in Florida now, then why are we now looking at having to go inland? I do not have the answer to that question; if anybody does, I would sure like to hear it.

PETER RHOADS

Let me give you one person's perspective on major plant construction, particularly along the southeast coast. We still have a fresh groundwater resource to develop. It is becoming more expensive because you have to move farther away from the saltwater interface in order to develop additional yield. It is a finite resource and we are approaching a safe yield limit, if the hydrogeologists will let me use that term. I think that you need to recognize that our problem is a seasonal problem because of our rainfall distribution. During the wet season, usually 9 out of 12 months, we have got plenty of water. It is during that critical dry season period, March, April, May, and sometimes into June, when we are going to be experiencing more and more short-term water shortages. So I think that it is mainly a peaking problem.

Until such time as the industry can demonstrate that the large scale RO plants are more economical, that their costs are lower than conventional water treatment plants, I do not think that we are going to see a large migration in that direction. But perhaps on the peaking side there is something not too far in the future to deal with the problem that many municipalities have along the coast. We can only continue to move in so far before we reach some other limits and, of course, quality questions.

STANLEY WINN

In respect to the size of the plants, we can give you some potential future scenarios looking way beyond the 20 and 30 mgd variety, maybe into the 100 to 200 mgd variety. As a result of very closely following what is going on in Yuma and other places, we hope to get the kind of data we need, rather than just these parametric curves which give you some very gross estimates, of what the cost of these larger plants are going to be.

For example, many of you have probably heard about the problems we are having with Lake Okeechobee. A technical committee was set up to look at various alternatives for removing nutrients from going into that very large lake. One of the alternatives that was considered by this technical committee was reverse osmosis. They really did not know about any of these other desalting methodologies, number one; and, number two, they did not know enough about reverse osmosis to really come up with a final recommendation as to whether or not it should be pursued for potential nutrient removal. The end result of this is that reverse osmosis is entered into the Lake Okeechobee Technical Committee final report as a question mark--requiring further analysis.

So far, because of the press and the urgency of getting things done as soon as possible, there has not been a lot of further analysis done to answer that question mark. A lot of that is due to only the parametric data that is available for these larger scale plants. But there is no question as data on larger scale plants, I am talking 100 mgd and beyond, become available that you are going to see potential applications develop for southern Florida. I do not know about the rest of Florida as you may not have the same kind of potential application.

The use of reverse osmosis and other desalination techniques as a secondary plus a tertiary stage for a wastewater reuse type of activity on a large scale, as is now used to hold back the saltwater in southern California, is a definite possibility in several areas within South Florida. Again, they are not going to sell to any political or even any socioeconomic- or environmentally-oriented organization until we have a lot better cost and technical data on just what these things are going to take to implement.

So we have got a ways to go but we are watching very closely what is going on throughout the rest of the world, not just in the United States. Hopefully we will see the development of these, especially as it regards the superb water quality you get out of the end of this system compared to most other water treatment systems. So all of you in the manufacturing, the industrial, commercial side of this, have got to keep the governmental agencies and certainly the local governments, aware of what these latest technologic capabilities are. That is what I said in the very beginning on this panel. We are sort of being bypassed to a great degree by the major corporations and I recognize the reasons for that. I am just saying this is the place that if you concentrate some more effort, you may get some payoff from it.

IAN WATSON

That is thought provoking and true. A problem is, and many of us have been down this road, that you talk to original equipment manufacturers (OEM's) or membrane manufacturers and there is not a single one in the business who has ever had a bad plant. Some may not be quite as good as others, but there has never been a disaster. But there are some skeletons out there.

AUDIENCE

If I may, that is why I was advocating demonstration projects. It is a necessary step. You have to convince them that this is not a magic word but that there are large scale desalting plants. In the United States, Florida has the best developed desalination plants but it is not the only location of desalting plants in the world. There are places with large scale desalination plants that exist. They are really enormous sizes and they are located in places where the total nation depends on the water from desalination. If you go to the United Arab Emirates, Kuwait, Saudi Arabia, these countries depend on desalinated water. Through the last 15 years now, they have depended on desalination. Included in this are large scale RO plants.

My company is involved in a $15 million seawater reverse osmosis plant. The contract price for it was only $2.75 per gpd installed. It shows how amazingly low the foreign prices can be on large scale seawater desalting plants. But I agree that brackish water is a first step to go in Florida. But there is a limit to the supply of brackish water. Down the road, seawater desalination is the answer and I would like to see if the South Florida Water Management District is interested in looking into seawater distillation.

PETER RHOADS

Along that line, one of the areas that I have heard concerns expressed before is on power costs and particularly, future costs. Given that the energy forecasting troops say that the cost of energy is going to go up over the next decade or so, how does that fit into the desal area. Can we look for some technology changes? Perhaps similar to what we saw with the low pressure membranes. Would one of you industry people or someone else be willing to speculate on that issue?

AUDIENCE

I could give you immediate numbers by comparison on seawater desalination today with the improved techniques as we have them and with energy recovery, the energy required is about 6 kW hours per cubic meter, that is about 24 kWhr per 1,000 gallons in total energy consumption. The worst case is about 8 kW hours per cubic meter.

This is still a significant cost but with energy recovery techniques which are being used in seawater installations, we have seen the energy cost really going down. I really expect that that is not going to hold down seawater desalting cost. The overall capital cost is still probably the predominant factor but in membrane cases, from my perspective, we are talking about certain capital, energy, and membrane replacement costs, which altogether as an absolute number will go down.

There are applications where membrane techniques are clearly the way to go, particularly on the brackish system, but down the road the combination of distillation and membrane techniques provide, in my opinion, the best hybrid combination. Because large scale distillation plants produce very high quality water, we are talking 25 ppm of total dissolved solids, you can combine them with the product from a seawater RO that produces water with a TDS of 1,000 ppm. By blending them together you get feedwater with a TDS of about 500 ppm. So the cost through hybridization and integration between these two processes could really reduce costs.

IAN WATSON

Now that goes back to your comment about power plant coupling and the use of waste heat. Let's move on. Anybody else. Comments, questions?

AUDIENCE

Just a comment. You indicated earlier a need for a separate category for a concentrate disposal and you have apparently taken the first step with this meeting down in Tampa. What can we do to expedite DER really doing something about it?

BILL CONLON

Mr. Shearer indicated in his letter that he was going to get back to me within six weeks and it is about that time. I am expecting a letter any day now. That is going to give us a rebuttal and I expect there are going to be other meetings, other workshops, in trying to get more definite solutions to each one of the categories where we are disposing our concentrate.

BILL HARLOW

Last Friday and Saturday there were about 800+ environmental lawyers that met over at South Seas Plantation on Captiva Island. I heard Mr. Jay Landers, who is the chairman of the Environmental Efficiency Committee, make a statement that they were going to do something about this classification.

IAN WATSON

Before we go on, the NWSIA white paper was mentioned. There are a number of copies of it on the table in the back of the room. It is interesting and I hope you will all pick it up and read it. I am sure that the authors, from NWSIA and the California Association of Reclamation Entities of Water (otherwise known as CAREW), would be interested if some of you want to comment in correspondence to them. So I encourage you to pick it up. They are getting ready to publish another one pretty soon.

Now, two people came up to me during the break and said they had significant comments to make. I do not see either one of them in the room.

JACK JORGENSEN

I was going to ask David Paul, who is the operator of a large concentrator, for some insight on his machine.

AUDIENCE

I am David Paul from New Mexico and I work at an 1800 megawatt coal fired power plant and if our regulations are anything that portend the future, I will have $140 million worth of water pollution control equipment. Out of 15,000 gpm that is the annual average discharge for the power plant, we have to either evaporate all of it or process it. So, about 12,000 gpm evaporates through cooling towers and then we have five vapor compression evaporators, a 3 mgd RO unit, plus 105 acres of polyethylene lined evaporation ponds for final disposal. We are a zero discharge plant and I guess we are kind of seeing that this may be something in the future where everyone is going to have to, from cradle to grave, take care of themselves. I will be glad to answer any questions, but we have had good luck with the vapor compressors. They are very energy intensive, they use 4,000 horsepower motors.

IAN WATSON

David, what do you do with the solids that you generate?

AUDIENCE

The solids now are all going through the evaporation cells. The cells are designed to hold the salt content of the 30 year life of the ponds.

IAN WATSON

Is this kind of like a nuclear waste disposal problem? At the end of 30 years what are we going to do with it?

AUDIENCE

Well, right now at the end of 30 years we will cap them. Ten years from now it may be a different regulation but right now we will be able to put a concrete cap on it.

AUDIENCE

I have got one question, being from out of state, what is the relationship between DER and the South Florida Water Management District, and what is the charter of these organizations?

PETER RHOADS

My understanding is that DER is currently moving towards an assistance direction. They still have a regulatory responsibility in that they are the primary environmental regulatory organization in the state. The water management districts also have some regulatory authority, considerably so on the water resource side where they are the primary regulatory agency; on the quality side, it is sort of split.

I think what we are hearing from the new Secretary of DER is that he wants to concentrate on a number of areas. He wants to concentrate on solid waste. We have some very significant and substantial problems in the state with solid waste and we do not have a well organized organizational entity to deal with them. I think Secretary Twachtmann has carved that out as one of his priority areas.

Wastewater reuse is another area where I have heard him indicate that he wants to see DER take a leadership role. That has been a critical one to the water management districts, as we have been sort of on the wire trying to figure out whether we need to take a role in that area or not. I think that is what we are hearing at the current time.

AUDIENCE

Are the two agencies both entities of state government?

PETER RHOADS

The way it is, DER is a department of the state under the State of Florida, they are a state agency. The water management districts are somewhat unusual creatures. There are five of them in the state. They are not state agencies, technically they are agencies of the state. The big difference is how they are financed.

The regional water management districts, almost unlike any other entity in the country, are regional multi-county agencies that levies an ad valorem tax. So, the water management districts are somewhat autonomous and from a financial viewpoint they are somewhat autonomous. They are governed by a nine member appointed board appointed by the Governor. In our district, the mission is that which Mr. Creel mentioned this morning: flood control, water supply, environmental protection, and water quality. It is in the water quality and the environmental protection areas that we are still sorting out with the new DER administration exactly where the lines are going to be drawn. One of the clear points though is that the Environmental Efficiency Committee and the new state administration under Governor Martinez has a clear direction to eliminate overlapping duplication. Not a very good answer but it is the best I can give you right now.

PETER RHOADS

I have another question. Kris Buros has emphasized strongly the need for good, competent operators of RO plants. What is the status of training and the operation of RO plants, the availability of good operators? Is it just a question of money? Where do we stand in that area?

AUDIENCE

I think that is one of the biggest problems we have in the RO industry right now is trained operators. We, in the City of Cape Coral, have been operating since 1976 so we have had a good proven background but I can imagine the problem for cities coming in, building an RO plant after running lime softening plants for so many years. What do you do? It is a completely foreign technology to them. That is unfortunately the way DER looks at it.

My operators have to be certified by the state, by DER, to operate the plant. They have to have a year's experience before they can even take their certification exam and that year's experience is in RO. They are gaining all that knowledge of RO but there is only one question on the test on RO. The rest is all on lime softening, so there is absolutely no recognition in the exam of RO as a process.

Now, I have heard from various people who want to set up good training programs, which I encourage. I cannot wait to see it come about as I think it is something that is lacking. But, I think something that would help us to possibly help the cities, or anybody who is going to build an RO plant, is to have a core of their operators trained ahead of time. To do this the owners would send those operators to a plant that is already operating. Have them come down and spend a month at that plant and let them work hand-in-hand with the operators who are already there. Give them some hands-on experience before they actually work in their own plant. Right now the City of Cape Coral just has a base pay, we do not have any special RO category, they are just water plant operators.

IAN WATSON

What kind of pay rates do the A, B, and C licenses carry?

AUDIENCE

I believe, C operators right now are starting about $5.50 per hour and a B can go anywhere from $6.00 to $7.00 per hour. When you get your A--now, these are bases--they are somewhere up to $8.00-$9.00 per hour. But if you stick it out for 4 or 5 years, you get your cost of living rate every year and you get your merit increases every year and after 4 or 5 years then it begins to become attractive.

Now, we used to have a very large turnover with the City of Cape Coral operators. They would come and go--I mean as fast as they were trained, they were gone. But now almost all of our operators have been with the City for at least 5 years and a lot of them are working on getting on towards 10 years, so you can see that the pay is starting to encourage them to stay. We have not had a new operator in probably over a year now which is a big accomplishment. All of our operators are licensed now by DER so we do not have any trainees any more but it has taken a long time to get there. I know if there were training programs in place it would really help out a lot.

AUDIENCE

I can only agree with what Mark said. The advantages we have had with our situation--we have had some good support from some of our manufacturers. The manufacturer of our electrodialysis plant, Ionics, has schooled some of our staff at their location in Massachusetts and we have found it very beneficial for the men. In our own particular situation, we have the experienced men help train the new men. I can really feel for utilities or cities building a brand new type of treatment plant without any existing plants or operators. I think the only solution is you go out in the marketplace and try to steal an operator from another plant, pay him a little bit more. It is a problem and we do recognize it.

IAN WATSON

What sort of turnover have you had over the last four or five years?

AUDIENCE

We have tried to increase their base pay and to give the operator some incentive and we have found this helped reduce the turnover. One of the problems that we have in our plant is that we have shift work which is certainly an undesirable thing for a lot of people. Nobody likes to work the graveyard shift. We try to compensate for this by paying premium pay and giving extra bonuses and time off. We have to work with the men to encourage them to develop careers and also to help them to develop their own personal life with increased salaries and other benefits.

BILL CONLON

I would just like to make a couple of points. One is that there is a school once a year at the TREEO Center, which is at the University of Florida. It lasts a whole week, and one day this year was strictly devoted to membrane processes, which I taught half of it and Stu McClellan taught the other half. In prior years, they have only devoted four hours to that. Outside of that, only once a year have the regional short schools of the operators association had anything. Some of the South Florida areas of the region have short schools that have a session on membranes.

I would suggest that for any new plant starting up, that they videotape the training that the membrane manufacturer or the OEM gives at the time they start up the plant. So when operator turnovers occur, they can just sit the operator down and as one part of the training, the operator would watch the videotape and get the same knowledge.

We were teaching at the one school that I know of that was involved in covering questions for operators on the exam. The operators hoped that the course would help them on the exams. We called DER in Tallahassee and asked them what they were using for exam questions and where they got their questions from because I did not know anyone in the industry who was furnishing them with good technical questions. They said that they get them from the Sacramento manuals which is a California study guide for water plant operators, which apparently covers a broad perspectus of water treatment plant operation.

There is a need for NWSIA, or one of our Florida associations, maybe in conjunction with manufacturers, to put together a good manual that could be sold as a training guide for desalting operators. Maybe the South Florida Water Management District would like to fund that or NWSIA can come up with some funds or whatever. It needs to be done.

Back when they formulated 17-16, which is the Florida Administrative Code which addresses operation, how many operators must be at a certain plant by license category, and the number of operators by the capacity of that plant, they really thought that RO, I can remember because they asked me about it, was a very highly technical process. Much more difficult to operate than lime softening. Prior to my 16 years in engineering, I worked 14 years in operation and maintenance of lime softening plants. I can tell you RO is a much simpler process to operate. At some of the plants, as a matter of fact, where there is a dual system like at Englewood and Venice with lime softening and RO, if you go in their plant and visit, you may not find the operator at the RO plant. He is over at the lime softening plant running alkalinities or watching his sludge blanket. These rules need to be reviewed also. Typically in operation staffing, it is whoever pays the best right now. We are stealing from somebody else.

IAN WATSON

One of the things that is very important, particularly for utilities that are getting into desalination, either RO or EDR or even nano-filtration, is that in the bid specs you should have a fairly comprehensive section on the requirements of the training program to be administered by whoever is the successful bidder on the equipment. It should be both classroom and hands-on. It should be a formal presentation with prepared text, videotaping is excellent because then you can replay it for your people over and over again. It is very important.

AUDIENCE

Do you remember NWSIA once proposed to get into the certification process?

IAN WATSON

We had a committee, Neil Cline, C.E. Pitts, and myself and we met twice I think, in Sarasota, and the whole thing kind of died.

AUDIENCE

Perhaps we should think this thing through again as undoubtedly the NWSIA presence here in Florida could generate such a committee and people on a paid, or reimbursement basis, who could create a certification program. This would work if the users could, after such certification, upgrade the operator's salary to provide incentive to get him to pass and get a desalting certification.

IAN WATSON

We talked to DER a year or more ago, about the possibility of developing a rider's certificate to be coupled with an A license which would make you a certified desalination plant operator. There was a lot of action on that for a while and then it kind of faded too.

AUDIENCE

I am a hydrogeologist. I am not in the field of RO but I understand that the National Water Well Association, in response to the high demand for water well technology and hazardous waste training, has taken a role in supplementing the EPA hazardous waste training with their own courses. It is only because of the demand that we have had that. It sounds like the demand for desalting is going to be increasing. With the need of RO plants in South Florida for trained RO operators, I imagine the demand will probably help facilitate the process of getting the certification process updated with the NWSIA throughout the country. I do not see why, if I am hearing everyone down here, people in this area could not set up something like that. But I think the demand will probably have to force that in this area.

IAN WATSON

We do run operator programs, not really training programs, but they are day long seminars similar to this. They are geared more toward operator personnel with introductory type things, a little water chemistry and how the membranes work, that kind of thing. They have always been very well attended down here. But we need to go a little further, you are right.

AUDIENCE

There was a lot of talk this morning about scale formation in RO systems and I suggest that someone come up on the podium who can talk about it in case questions come up. I was struck by one of the representatives of the local press corps looking at a highly calcium sulfate fouled membrane and he was wondering if that was going to happen to any new construction here. Thanks to Al Florez, from Hydranautics, who was standing there and he told him that this was basically a misoperation situation. I hope that you resolve this situation with the press because it could be an awfully bad turn of events if something like, "The technology that they are proposing here is going to set up like a rock," got into the local newspaper. It is equally bad for us who supply chemicals to keep that from happening.

I want to make one other comment, sort of relative to what Bill Hendershaw was saying, in addition to what he was saying about operation and maintenance. It stems from an awful lot of phone calls that I have received that say, "How much FLOCON-100 do I need to put into this system? I have a total dissolved solids of 3,000 and my hardness is somewhere around 700."

My response is generally, "Well, how much calcium do you have? How much magnesium do you have? What is the constituents of the rest of your raw water feed?" The basic design of any RO plant, as most of these guys will attest, starts with a really decent analysis of the water that you intend to process. I, for one, get a lot of calls from somebody who does not have any idea of what they are starting with. We do water analysis, I prefer not to do water analysis, we will do it if you want, but for crying out loud, if you are going to take the time, the effort, the money, to invest in a reverse osmosis plant, then spend $150 to $200 and get yourself a complete and accurate analysis of the water that you have to process so that those of us who supply the chemicals can make some reasonable assessment and prevent these accidents from happening. The membrane manufacturers can make some reasonable assessment of what to expect from their equipment, etc. It is very cheap, there are plenty of labs around that can do them for you. Do not be chintzy and try to get something for $50 that should cost $150 or something like that--spend a little money upfront and you will be very pleased.

BILL HARLOW

I would also like to put in a suggestion to anybody who is thinking about building a reverse osmosis plant. One of the things that we at Englewood did when we designed our plant was that we told our engineering firm to put in an adequate space for a laboratory and to equip it. It has paid off for us.

Our budget for the support of our laboratory, including our chemist, is right around $65,000 a year. Just this past week because we are in the budgeting process, we took a look at the number of samples that we are running and what those would have cost us if we had sent them out to an outside laboratory and it would appear as though it would have cost us over $200,000 if we were to run the same number of samples using outside services. You can use those numbers as an example of the savings that you can have by having your own laboratory.

I can also say this. If we did not know where we were going from day-to-day with our analysis, we would be lost.

IAN WATSON

Any more comments or questions?

AUDIENCE

I have a question that is not really related to the problem. It is addressed to membrane manufacturers in the way that membranes are being manufactured, from high pressure a few years ago to the present low pressure. Is it still going to go down? What is the general direction of the membranes being manufactured? Will it ever get the pressure down to 100 psi or less for brackish water?

DAVID FURUKAWA

As a manufacturer, that is a question that has been asked many times, particularly within the last year when we have seen membrane technology take a considerable leap forward with the advent of low pressure membranes. Aside from the membrane itself, there are some physical limitations of the hydraulic equipment, the mechanical aspects of getting water to and through a membrane. There are certain friction and pressure losses incurred within the membrane and those are really quite limiting.

Membranes are taking a tremendous leap forward in every company around the world, not just here in the United States. Recently there was a meeting in Japan and there was an awesome quantity of data presented on new membranes. Hermann Pohland showed you this morning some of the membrane materials that are presently being examined and commercially available. Think back maybe 10 years ago when we had the NWSIA meeting in Sarasota. How many membranes were available at that time? Two. Look at the wide array of membranes that are available today. All I can see is that the amount of research that is being put into new membranes, not just for desalination but for separations of all types having to do with fluids and gases, is tremendous.

There is a tremendous amount of energy, money, and talent being poured into membrane research. I have no doubt that the technology is going to continue to improve. Whether it improves in the area of further reduction in operating pressure or not is questionable. I think we are going to reach the physical limits pretty quickly. On the other hand, I think there is going to be a continued improvement in chemical resistance of membranes, prevention of oxyidative effects on membranes, perhaps membranes that will perform separations that we are not aware of today. It will be very helpful to all of us.

The nano-filtration membrane is a good example. This is just an offshoot of ultra-filtration and reverse osmosis technology but we are finding out, thanks to a lot of the work that is being done right here in Florida, that the membranes have characteristics that we did not think it had. Removal of THM precursors and other such things. I think you are riding the crest of some tremendous technological developments in membranes. All I can say is, it will only help this technology in the future.

IAN WATSON

Does that answer your question? Any more questions, comments? Are there any utilities or water districts or purveyors of water utilities who are considering building one of these plants? Any others? One? What are all the rest of you guys doing here.

AUDIENCE

One comment. I am from the Southwest Florida Water Management District. I have recently attended a course that Pinellas County has studying desalination potential. One thing that impressed me that was brought up was they have a resource recovery plant. I think Mr. Conlon mentioned the amount of material we bury in landfills. Currently, they burn material and they generate power and sell this back to the power grid. It was pointed out by a consultant that they could turn that energy around for a much better price for their own use or for a distillation process since they are looking at the potential for desalting water.

They do not get a very good return when they sell the power into the grid. They get a very low price. So they could use that electricity for RO and they could use the waste heat for distillation if they wish. West Coast Regional Water Supply Authority, I do not know if there are any other people here from that group, but they are currently studying the best technology for RO in their system.

IAN WATSON

Okay. Does anybody want to make a last comment or last question? That is it. Thank you all.

SEMINAR SUMMARY

by

David Furukawa
Vice President, Western Operations
FilmTec Corporation
San Diego, California

DESALINATION IN SOUTH FLORIDA
August 21, 1987

SEMINAR SUMMARY

by

David Furukawa
Vice President, Western Operations
FilmTec Corporation
San Diego, California

Trying to summarize a meeting like this is always quite difficult because there are so many subjects that have come up in the course of a day that have tremendous interest for different groups of people. But I must say that I was very pleasantly surprised at the number of people who came here to discuss these problems today. I think that the number of things we learned and the number of problems we learned about today are significant.

I learned a lot about Florida. Coming from California, we know that we have a lot of problems on the West Coast of the United States. I found out today that you, here in Florida, have your own share of problems and I was very pleased that I was able to come here and learn about some of them.

Florida, like California, is a state that is undergoing a fantastic growth rate and you have some of the same problems that we do in California, such as seasonal variations in the water supply. You recognize the need to develop alternative water sources by looking at water reuse and desalting. I have heard a couple of times, from various people, how important it is to Floridians to maintain the quality of life.

The efforts of the South Florida Water Management District were discussed in looking at the supply and demand management pictures, things like rate structuring and the fact that 90 percent of your water supply does come from groundwater sources. Some of the strategies that you have taken in looking at potential solutions were

This paper was prepared by the editor based on a recording of the presentation. Where deemed appropriate, the presentation has been edited for clarity.

outlined. This morning you discussed the problems associated with backpumping and raising the lake level in Lake Okeechobee. The importance of well field development and making sure that the groundwater level in well fields is not overly taxed was emphasized. We have similar problems with well field development in California.

In the San Joaquin Valley of northern California, they have experienced considerable problems in land subsidence, not just the fact that we do not have water but the fact that land has actually subsided. So, all of these things do create problems and you are very much aware of them. I was really interested in learning about these problems. How do we solve these problems?

From what I can observe, many of these problems that have been discussed including deep well disposal of concentrates from RO systems, they seem to point to the examination of various techniques such as desalination. This appears to be a reasonable solution to many of your water problems here in the state. But to use the technology, we have to be able to know what the technology means and how to use it.

We just had some comments a few minutes ago that much of this information perhaps has not been made available to the government agencies here in the state, or municipalities, or to utilities. We hope that not only we, as manufacturers or the consulting engineers that are present, but perhaps the National Water Supply Improvement Association as an organization, can play a part in somehow fostering the communication which will get the information to you. Because as others have pointed out, there is a wealth of information out there.

We always run into a problem in this industry and this has been true for many, many years. We try to show you how simple these processes are and as we went through the basic principles of desalting this morning, I hope that Dr. Buros and others were successful in letting you know that they are basically simple processes but being good engineers, they also tried to tell you that if you are not careful, you are going to have a problem. And this is where we have a bit of a conundrum because how much of these problems do we relate to an audience? You want to tell them the truth but you do not want to over-simplify nor do you want to over-magnify the problems.

Scaling in membrane and thermal systems have been basic process problems for decades. But on the other hand, process technology has advanced enough that good engineers and good designers can help you to properly design and build your systems so that you do not run into these kinds of problems. So we have a problem perhaps with being too truthful sometimes.

I just want to leave you with a note that really some of the scaling and other problems that we have talked about are certainly problems to be aware of. But with good engineering and with good technology that is available, those problems can be solved for you.

As we went through this day, I certainly am left with the clear impression that reverse osmosis and electrodialysis may be the processes that have the most application to Florida's water problems. Probably because the cost of operating these processes is the most economic of the several processes.

One of the areas that we talked about was the disposal of concentrate. We must focus our thoughts and energies into finding a really reasonable method of solving the concentrate disposal problems, otherwise it is going to hold up the development of desalting in this state. We have the same problem in Colorado. I am sure the same problems occur in New Mexico where David Paul comes from and in other states. But, nonetheless, it is a real problem and it is not really as technology-related as it is related to regulatory agencies. I think we can all play a strong part in helping solve that kind of problem.

The consulting engineers and South Florida Water Management District have had their share of interface with DER regarding desalting. I know several of us manufacturers have had our own relationships with DER. It occurs to me that perhaps we might all get a little further in this process if we were to get together a bit, talk over the magnitude of the problem as was done a week or two ago when Bill Conlon got a group together. Perhaps you should develop a task force that includes water management agencies, consulting engineers, utilities, and manufacturers. It is just a suggestion. Maybe this would help us overcome this resistance that we are presently feeling.

There is no question that Florida is the center of membrane installations in these United States. You have over 100 operating plants here that represent somewhere between 30 and 50 mgd of operating capacity. Although the United States government is building the Yuma desalter, which will eventually have 72 mgd of capacity in one location, it is not operating yet and it may be a few years before it ever does. But you here, in the state of Florida, have led the way in building and operating plants. As a result, you also have within your grasp probably more operational experience on RO, EDR, and ED plants than anybody in the United States and that is worth a lot. I think that you are very fortunate in having that kind of information right here within the State of Florida. I have no doubt that there are tremendous resources here in Florida, many of them sitting right here in this room. I would challenge everyone of you that feels that you do not have enough information to contact these very people.

We learned today that the selection of a particular process is very site-dependent, very site-specific. As a result, it is very difficult to relate the cost of one plant to another. But I think, in general, you got the idea. To build a good plant you need to have good planning. You have to have good specifications that outlines to the people bidding on the plant just what is going to be in the plant, what is it expected to do, and what is the manufacturer expected to do. I would ask you one thing, speaking as a manufacturer, and that is, please do not make your specifications on the membrane manufacturer so difficult that they cannot bid on your project. After all, even membrane manufacturers have certain limits to their resources and ability to comply with certain warranty requirements.

As we went through the program, it emphasized one of the most important aspects of desalting and that is, the operators. We talked about operator training and heard from operators like Mark Ashton and Dick Derowitsch. You saw the value of good data collection like Mark was showing you on his various slides today, that allows you to go back through the years and determine how well your system has been operating. It lets you compare what you are doing today with five years ago. The little things like Dick told you about in terms of maintenance, keeping up your plant and that, in many cases, it is probably more economic to upgrade an existing plant than to go out and buy a new plant. There is an awful lot of knowledge here and I was really impressed.

I could probably go on for much longer but I will really cut it short and just say that the amount of information available right here in your own state, not only is it significant, but it is awesome. You have a good number of consulting engineers, architect/engineers, available to you. You have tremendous knowledge in operating plants around the state and I would urge you to try to pool that talent somehow. I hate to be talking about another organization but perhaps there is a way of getting you all together in some kind of regional organization that might be helpful to everyone concerned.

Lastly, however, I would like to pay my thanks to the South Florida Water Management District for putting this together. Their support of a problem like this is invaluable to everyone who takes the time to come here. I would encourage all of you to participate in future seminars and workshops that will be put on by the National Water Supply Improvement Association. We have a national meeting coming up in San Diego in August, 1988. I would encourage you all to come to that meeting. In fact, I would really encourage all of you that have operating plants here in the State of Florida to consider putting together a technical paper describing what your experiences have been and perhaps we can include them in some way in this meeting in San Diego. I think it would be very valuable to everyone.

I cannot help but make a sales pitch. I would encourage you all to join NWSIA. We are a fast growing association which is concerned about national and regional issues such as we have talked about here today. I hope I have been of some help in summarizing some of the thoughts and ideas expressed today.

I would like to acknowledge that the concept of this seminar is the brainchild of Nagendra Khanal, of the South Florida Water Management District, who thought of it about a year ago. He followed through, got it organized, and got us going. So we thank him very, very much and certainly thank the South Florida Water Management District for their support.

Thank you all for coming.

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DESALINATION IN SOUTH FLORIDA

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BIOGRAPHICAL INFORMATION

MARK ASHTON is the Water Production Superintendent for the City of Cape Coral, Florida. He is responsible for the operation of a 15-mgd RO plant, water distribution, budget preparation, and control of expenditures for new equipment and maintenance. Mr. Ashton holds a Florida Class A license.

O. K. "KRIS" BUROS is the Manager of the Water Resources Division of the consulting firm of CH2M HILL in Gainesville, Florida. Dr. Buros is the author of the widely used text, The U.S.A.I.D. Desalination Manual. He has been active in a number of desalination studies in the eastern U.S. and the Caribbean.

WILLIAM CONLON is a Senior Project Manager for Post, Buckley, Schuh, and Jernigan, Inc., in Ft. Myers, Florida, and is responsible for the design and management of engineering projects. He is currently working on membrane process studies for the City of Boynton Beach and the Acme Improvement District.

TILFORD CREEL is the Deputy Executive Director for the South Florida Water Management District. Formerly, Mr. Creel was in charge of the Corps of Engineers Waterways Experiment Station in Vicksburg, Mississippi.

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DAVID FURUKAWA is the Vice President for Western Operations for the FilmTec Corporation in San Diego, California. He has been active in desalination technology for over 25 years and is a past president of NWSIA. FilmTec is an RO membrane manufacturer which has supplied membranes to a number of plants in Florida.

HOWARD "BILL" HARLOW is the Manager of the Englewood Water District (EWD) in Englewood, Florida. The EWD has a 1.5-mgd reverse osmosis plant and a lime softening treatment plant as part of its facilities. Mr. Harlow is the President of the NWSIA.

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